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ABSTRACT

The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), has developed a document governing energy usage in all types of new construction: ASHRAE Standard 90-75: Energy Conservation in New Building Design (ASHRAE 90). To lay the foundation for an evaluation of ASHRAE 90, the Federal Energy Administration (FEA) retained Arthur D. Little, Inc. (ADL), to investigate the potential energy and economic impact the standard would have on the nation's construction industry. It was the intent of the study to quantify those impacts in the energy and economic sectors as well as possible, and to qualitatively assess their impact in the institutional sector. Within the report are many findings, observations, and recommendations concerning ASHRAE 90's effect on building energy consumption, its influences on physical changes in the buildings, its implications on the owning and operating costs of buildings, its potential impact on the nation's energy consumption in construction, its possible economic impact in several selected markets and participants within the construction sector, and its impact on building habitability. (Author/MLF)

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ED140508

Energy Conservation in New Building Design

An Impact Assessment of ASHRAE Standard 90-75

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PREFACE

The Federal Energy Administration (FEA), through its mandate from Congress, is active in investigating those areas related to the energy and economic impact due to the adoption of reference codes to promote energy conservation in buildings. One recent effort in developing a document governing energy usage in all types of new construction was undertaken by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) following a request by the National Conference of States on Building Codes and Standards (NCSBCS) in February, 1974. During the past eighteen months, ASHRAE has undertaken a methodological approach in developing a voluntary standard. They have issued two working drafts for public comment and subsequently fielded numerous suggestions for improvement from both ASHRAE members and other representatives of the design/construction industry. Now in its final form, the document is entitled, ASHRAE Standard 90-75: ENERGY CONSERVATION IN NEW BUILDING DESIGN, and was released by ASHRAE's Committee on Standards in August, 1975.

To date, ASHRAE 90-75 is the first major voluntary consensus standard concerning energy utilization in new buildings available for optional acceptance by the individual state and local governments even though the standard has yet to enter the approval process of the American National Standards Institute (ANSI). Both its format and much of its content is based upon a previous document released in February, 1974, by the National Bureau of Standards (NBS), again at the request of NCSBCS.

To lay the foundation for an evaluation of ASHRAE 90-75, the Federal Energy Administration (FEA) retained Arthur D. Little, Inc. (ADL) in May, 1975, to investigate the potential energy and economic impact the standard would have on the nation's construction industry. This included an investigation of the effects on building energy consumption for a variety of building types and geographical locations, the effect on initial (capital) and operating costs of new buildings, the possible influence on building habitability, the reduction in the nation's annual energy requirements, and the potential economic impact on selected sectors within the construction industry. This latter task was to include several selected subindustries dealing in commodity building materials and specialty equipment in addition to key industry participants such as residential homebuilders, architectural and engineering firms, code authorities, etc.

The primary objective of the study was a detailed understanding of all the implications brought about by the possible widespread adoption of ASHRAE 90-75 as a voluntary energy conservation standard. It was not within the scope of work to either technically evaluate ASHRAE 90-75 or to make a case for or against its adoption as an energy conservation guideline.

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CHAPTER I

EXECUTIVE SUMMARY

A. OBJECTIVES

The purpose of this investigation by Arthur D. Little, Inc. (ADL), was to analyze the various energy, economic, and institutional impacts that might occur following the broad voluntary adoption of ASHRAE Standard 90-75[1] by individual building regulatory authorities. It was the intent of the study to quantify those impacts in the energy and economic sectors as well as possible, and to qualitatively assess their impact in the institutional sector.

B. METHODOLOGY

In order to study the applicability and impact of the document to each of the foregoing, ASHRAE 90 was subdivided into three approaches to facilitate the analysis:

- *Standard Prescriptive/Performance Approach (Sections 4-9)*: Well-defined performance criteria, based upon an element-by-element design analysis, are applied in this approach to the selection of building materials and systems.
- *Systems Analysis Approach (Section 10)*: An alternative to the above, this approach allows for compliance if the building's energy consumption is shown to be equal to or lower than that achievable through the standard prescriptive/performance approach of Sections 4 through 9.
- *Energy Augmentation Approach (Section 11)*: This alternative allows for the use of solar- or wind-powered systems, or other nondepletive energy sources, to supplement the energy usage of the building by including a "credit" for the energy supplied by such systems.

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[1] Called ASHRAE 90 hereafter, this refers to the document entitled, "Energy Conservation in New Building Design," the final draft of which was released in August, 1975. Major modifications made to the document after this date could not be incorporated into the analysis.

The quantitative analysis focused on the first and third approaches.[2]

ASHRAE 90's impact on the construction industry in general and on energy consumption, initial cost, and operating costs of projects in particular was determined on the basis of impact on each of five types of buildings in one location in each of the four major census regions. The five building types investigated were:

Single-Family Detached Residence
Low-Rise Apartment Building
Office Building
Retail Store
School Building

Thus, there were 20 prototypical building type/location projects investigated. The study results represent the maximum impact which would occur under adoption of the standard.

For each case, ADL estimated annual energy consumption using established manual methods for single-family residences and computer-based simulation techniques for nonresidential structures. Two sets of calculations were made: one for the "conventional" building and one for the "ASHRAE 90 modified" building. Next, the comparative impact of ASHRAE 90 on each of the following was determined.

- Physical characteristics of the building,
- type and amount of commodity building materials,
- HVA/C[3] system size and configuration,
- annual energy consumption (by end use),
- annual operating economics, and
- initial capital cost of the project.

On the basis of the resulting data and the data base developed in a previous ADL report,[4] estimates were developed of the impact of ASHRAE 90 on total energy demand within the building sector for the period 1976 to 1990.

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[2] The full report, however, does discuss the implications of the systems analysis approach on design architects and engineers.

[3] Heating, Ventilating, and Air-conditioning.

[4] "Residential and Commercial Energy Use Patterns, 1970-1990," Arthur D. Little, Inc., report to the Council of Environmental Quality and the Federal Energy Administration, November, 1974.

The impact of the standard on the construction industry was evaluated by subdividing the industry into several subsectors and applying the changes in initial cost and/or demand for building materials and specialty equipment compiled from the 20 prototypical examples. These subindustries can be roughly categorized into three groups:

Building Materials Suppliers:

- Insulation
- Siding Materials
- Windows
- Window Glass

Building Equipment Suppliers:

- Electric Lamps
- Lighting Fixtures
- Gas and Electric Meters
- Hot Water Heaters

HVA/C Systems Suppliers:

- HVA/C Equipment
- HVA/C Controls

In addition, the potential impact of the standard on residential builders and developers, architectural/engineering design firms, and code authorities was also investigated.

Finally, the impact of ASHRAE 90 on indoor air quality was evaluated through an extensive literature search, consultation with outside experts, and the in-house expertise of ADL in this area.

C. KEY ASSUMPTIONS

The continuing scarcity of data on building energy usage, the generally poor economic condition of the domestic construction industry, and the fact that ASHRAE 90 had to be interpreted for the first time in a design situation required that several critical assumptions be made:

Interpretation of the Standard: For the purposes of this analysis, a strict interpretation of ASHRAE 90's impact on the conventional buildings was adopted. As an example, where the document only "recommended," rather than "required," that certain measures be taken, the recommendation was interpreted to be a requirement. This leads to the maximum impact on the conventional design process.

"Conventional" Buildings: The configuration, materials composition, physical characteristics, and HVA/C systems selected for the "conventional" buildings represent that which was considered typical in new construction. For the most part, selections were based on various public and proprietary statistics. The buildings should be considered "prototypical," since there is no such thing as an "average" building. The actual operating conditions of the "conventional" building were assumed to reflect the conditions prevalent within the construction industry prior to the oil embargo of 1973/74, and might be referred to as "1973 vintage" conditions. Using this period as a benchmark is consistent with other policy studies undertaken by FEA, and emphasizes the rationale for investigating the maximum impact as conservation-oriented design changes within the construction industry have become more prevalent since 1973. Inasmuch as ASHRAE 90 does not dictate how buildings should be operated, the identical operating conditions were retained for both the "conventional" and the "ASHRAE 90 modified" buildings.

"ASHRAE 90 Modified" Buildings: In modifying the prototypical conventional buildings to meet the requirements of ASHRAE 90, the principal criterion for making the decision among alternatives was initial building cost with the rule being to select that alternative which offered the minimum effect on initial building cost. To maintain the aesthetic looks of the building, minimum limits on glass areas were adopted. When confronted with a trade-off in this area, the composition of the opaque wall was changed rather than any further reduction of fenestration.

A second consideration in modifying the conventional buildings was the amount of change needed in component performance. The philosophy employed was to meet, but not purposely exceed, the standard since a client and/or members of the design community would most probably not choose to adopt major modifications in either building appearance or system performance. To determine the economic consequence of exceeding the standard was beyond the scope of this study.

Construction Industry: The analysis of the impact of ASHRAE 90 on the various markets for materials and equipment was based upon an ADL forecast of the construction industry in 1976. ADL assumed a slight rebound in residential housing starts to 1.5 million units, and a leveling of nonresidential construction activity until late 1976.

D. CONCLUSIONS

Within the report are many findings, observations, and recommendations concerning ASHRAE 90's effect on building energy consumption, its influences on physical changes in the buildings, its implications on the owning and operating costs of buildings, its potential impact on the nation's energy consumption in construction, its possible economic impact on several selected markets and participants within the construction sector, and its impact on building habitability. The more important conclusions are as follows:

1. *Impact on Building Energy Consumption*

Under a strict interpretation of the standard, ASHRAE 90 is very effective in reducing annual energy consumption in all building types and locations. The unweighted average reduction in annual energy consumption relative to 1973 construction and operational practices across the four locations investigated were as follows:

Single-Family Residence	- 11.3%
Low-Rise Apartment Building	- 42.7%
Office Building	- 59.7%
Retail Store	- 40.1%
School Building	- 48.1%

ASHRAE 90 may be seen as less effective in reducing annual energy demand in the detached single-family residence than in the larger residential and nonresidential buildings. This lower effectiveness may be explained in part by the moderately high overall thermal efficiency assumed for the conventional residences. However, the ASHRAE 90 modified residences in both the Northeast (New York City), North Central (Omaha) locations met the standard with single glazing and a minimum reduction in glass area.

The standard appears to be more effective in the colder climates because of the larger percentage of annual energy demand in all construction accounted for by space heating and the inherent effectiveness of ASHRAE 90 in reducing annual heating requirements. In general, the decrease in space heating requirements accounted for 60 to 75% of the total reduction in actual energy consumption.

The lowest unit-energy consumption obtainable in the prototypical buildings after the prescriptive/performance approach (Sections 4 through 9) had been made was on the order of 67,000 to 72,000 Btu per square foot. This consumption is considerably greater than the General Services Administration announced "goal" of 55,000 Btu per square foot. ADL does not believe the implementation of ASHRAE 90 alone would suffice to meet the GSA goal for any building type similar to those investigated.

If measured in terms of energy reduction potential, the most "effective" sections in the document will vary by type of building. With few exceptions, all of the sections have some influence on the reduction in annual energy consumption. Changes in winter design conditions (Section 5) and supplied domestic hot water temperatures (Section 7) appear to be the most effective parameters for the single-family residence, while those chapters dealing with HVA/C equipment, systems, and control (Sections 5 and 6) appear to be most effective in nonresidential construction.

2. *Impact on Physical Characteristics*

The application of ASHRAE 90 brought about the following physical differences in the conventional versus ASHRAE 90 modified buildings:

Exterior Glass - Glass area (percent fenestration) was reduced in approximately two-thirds of the buildings. Reductions were as much as 30%, but most were less than 20%. One region--the North Central--required reductions in glass area for all buildings.

Exterior Wall - Decreases in glass area were balanced by increases in net wall area; virtually all increases were less than 8%.

Insulation - Additional insulation requirements for residential construction varied from 80 to 300 pounds per unit. Increased requirements for insulation in commercial construction were even greater than those needed in residential construction.

Lighting - Reductions in lamps and lamp fixtures varied by building type, and averaged 24% and 22%, respectively, for nonresidential construction.

HVA/C System Capacities - Reductions in heating system capacities were significant, averaging 42%, while reductions in cooling systems were generally less, averaging 31%. The greatest reductions were found in the school building. Auxiliary HVA/C equipment, including pumps, towers, fans, supply fans, etc., also showed a significant reduction, averaging 44% in rated kilowatt capacity.

3. *Impact on Building Economics*

Based on 1975 energy costs compiled by ADL, annual savings in operating costs ranged between $0.05 and $1.05 per square foot, but were generally within the range between $0.20 and $0.70 per square foot. Savings in single-family residences ($0.05 to $0.14 per square foot) were lower and less broader than those for commercial construction ($0.12 to $1.05 per square foot). Percent savings in annual energy costs ranged from 9-15% in the single-family house to 30-45% for commercial buildings.

The savings may be large enough to induce building owners to follow the standard on a voluntary basis providing they had such decision information available to them and providing financial institutions recognize that the loan quality is improved.

The initial construction costs of those buildings modified under the standard prescriptive/performance approach were shown to be less than those of conventional buildings. Unit savings range from $0.04 to $0.94 per square foot, with the greatest savings experienced in office buildings.

ASHRAE 90 generally increases the cost of the exterior wall, floors, roof, and domestic hot water system. Glazing costs may be higher or lower depending upon building type. Unit costs for lighting, and particularly HVA/C equipment and distribution systems, were signficantly lower and tended to offset the increase in other costs.

Average changes in unit costs are as follows:

	Dollars Per Square Foot
Single-Family Residence	- 0.02
Multi-Family Residence	- 0.41
Office Building	- 0.63
Retail Store	- 0.18
School Building	- 0.44

For the prototypical buildings investigated, the cost of additional design effort was found to be between $0.09 and $0.36 per square foot of floor area. With the exception of the single-family residence, the straight payback of design services due to energy cost savings was found to be less than one year, and less than six months in most cases. Average additional design costs were as follows:

	Dollars Per Square Foot		
	Annual Energy Savings	Additional Design Services	Straight Payback
Single-Family Detached Residence	0.07	0.24	2.9 years
Low-Rise Apartment	0.31	0.09	3.4 months
Office Building	0.40	0.16	2.5 months
Retail Store	0.68	0.09	7.6 months
School	0.70	0.15	4.6 months

Thus, savings in initial cost can be offset by increased design fees; consequently it appears that the ASHRAE 90 modified buildings should cost no more to build and will have significantly less annual energy costs. Furthermore, even if total initial cost did increase, the savings in operating cost (over those of conventionally-designed buildings) would more than recover such costs in a couple of months.

4. *National Energy Consumption*

If instituted by all states, ASHRAE 90 could reduce the annual energy consumed in new construction by about 27%, and if instituted in 1976, the standard would reduce ADL estimates of the growth of energy consumption in the building sector over the period 1976 to 1990 from 2.3% to 1.4%.

The potential energy which could be saved by the adoption of ASHRAE 90, equals 4%, 8%, and 12% of total estimated annual energy consumption in the nation's buildings for the years 1980, 1985, and 1990, respectively. However, the standard will not cause a decline in the nation's future demand for energy in the building sector.

The potential energy saved by ASHRAE 90 was found to be greater in the North Central region, and again, this is related to the annual demand accounted for by space heating.

ASHRAE 90 could reduce energy consumption significantly even if it were adopted (and enforced) only by those 29 states that presently have mandatory or voluntary statutes or that have bills pending, since 75% of the volume of affected construction lies within these 29 states.

5. *Impact on Building Materials and Building Equipment Markets*

Of the estimated $168.5 billion in construction expenditures in 1976, the study estimates $88.3 billion, or 52%, could be affected by ASHRAE 90. Of this, $80.0 billion is construction put-in-place, and $8.3 billion is attributable to mobile homes.

ASHRAE 90 would upgrade the building's thermal shell, lower lighting and ventilation levels, and reduce HVA/C equipment capacities. The direct economic impact attributable to ASHRAE 90 appears to be limited to a few specific industry sectors. (See Table I-1.) In general, the adoption of ASHRAE 90 will create opportunities for suppliers of commodity building materials at the expense of reducing those markets for general building equipment and HVA/C systems.

The most favorable impact appears to be on building insulation suppliers, who could realize as much as $179 million in new markets, an increase in their overall annual sales of approximately 18%. Likewise, HVA/C equipment manufacturers face an annual potential loss of $185 million, 8% of their total market, while lighting fixtures manufacturers

TABLE I-1

SUMMARY OF ECONOMIC IMPACTS DUE TO ASHRAE 90

	Total Annual Market ($MM)	Market Affected by ASHRAE 90 ($MM)	(%)	Maximum Potential Impact by ASHRAE 90 ($MM)	Percent of Total Market (%)
Building Materials Suppliers:					
Insulation:	1,000	595	(60)	+179	+18
• Batt	470	270	(57)	+ 45	+10
• Rigid Board	460	280	(61)	+128	+28
• Loose Fill	70	45	(64)	+ 6	+ 9
Siding Materials	1,000	850	(85)	+ 12	+ 1
Flat Glass	1,247	146	(12)	+ 7	+ 1
Windows	903	720	(80)	- 19	- 2
Building Equipment Manufacturers:					
Electric Lamps	1,177	176	(15)	- 16	- 1
Lighting Fixtures	1,450	830	(57)	-175	-12
Gas and Electric Meters	173	159	(92)	+ 3	+ 2
Hot Water Heaters	289	117	(40)	+ 4	+ 3
HVA/C Systems Manufacturers:					
HVA/C Equipment	2,308	1,720	(75)	-185	- 8
HVA/C Controls	550	410	(74)	+ 21	+ 4

SOURCE: Arthur D. Little, Inc., estimates.

TABLE I-1

Y OF ECONOMIC IMPACTS DUE TO ASHRAE 90

Market Affected by ASHRAE 90 ($MM)	(%)	Maximum Potential Impact by ASHRAE 90 ($MM)	Percent of Total Market (%)	Percent of Affected Market (%)
595	(60)	+179	+18	+30
270	(57)	+ 45	+10	+17
280	(61)	+128	+28	+46
45	(64)	+ 6	+ 9	+13
850	(85)	+ 12	+ 1	+ 1
146	(12)	+ 7	+ 1	+ 5
720	(80)	- 19	- 2	- 3
176	(15)	- 16	-.1	- 9
830	(57)	-175	-12	-21
159	(92)	+ 3	+ 2	+ 2
117	(40)	+ 4	+ 3	+ 3
1,720	(75)	-185	- 8	-11
410	(74)	+ 21	+ 4	+ 5

es.

face a potential loss of $175 million, 12% of their total market. The remaining market sectors will receive only a minimal impact, typically ranging from -2% to +4% to their annual market.

HVA/C equipment manufacturers, unlike commodity materials suppliers, are heavily oriented towards new construction. Few, if any, large secondary markets are available to HVA/C component suppliers that can offset a major loss in the potential sales volume from conservation-oriented design. Although manufacturers may be able to moderate this negative impact, they will nevertheless be adversely affected by any type of effective energy conservation legislation, be it ASHRAE 90 or some similar design standard.

Most of those companies associated with the construction industry have experienced other sudden and significant impacts on their markets and still survived. The situation investigated here is comparable to those sudden annual downturns resulting from annual residential cyclicality or safety-oriented fire modifications. ADL anticipates these sectors will again be able to adapt.

6. *Impact on Key Industry Participants*

The study concludes that the successful implementation of ASHRAE 90 will have an insignificant impact on residential homebuilders. Large builders can meet the standard at an insignificant design cost, and the small, local builders--while initially experiencing difficulty in interpreting the document--will probably be assisted by the local Homebuilders Association or building materials suppliers through manuals of accepted practice.

Wise builders seeking profit opportunities on sales may well use the energy crisis as a sales tool to sell extras, but these, for the most part, will have to be visible.

The adoption of ASHRAE 90 will tend to load-up the "front end" of the design process. It will result in more calculations, further technical and economic evaluation of systems, additional internal and external meetings of the design team, and more interaction with code authorities. This effect on the design process need not affect the project schedule, provided that the mechanical engineer is included in the design team at the very beginning.

ASHRAE 90 will generally encourage the use of electronic computation on all projects, and thereby create a major market for energy-oriented computer programs and services.

Total A/E design billings in 1976 are estimated to be $7.4 billion, approximately 40% of which could be affected by ASHRAE 90. The net impact of adopting the standard would be a potential increase of $92 million in billings for mechanical/electrical engineers and $60 million for design architects. It seems likely that the A/E's ability to collect for additional services will depend strongly upon the health of the construction industry at the time.

Perhaps more than any previous event in the design industry, the advent of ASHRAE 90, or some similar standard, will demand a major overhaul in the industry's fee structure, particularly for mechanical/electrical design engineering services which historically have been based on a percentage of the mechanical systems cost of the project.

From a professional standpoint, possibly the most significant impact of ASHRAE 90 is that the design engineer will become a more important and integral member of the design team.

Concerning code authorities, ASHRAE 90 faces two problems: implementation and enforcement. It would not be surprising if a standard dealing with an abstract objective--achieving national energy self-sufficiency--were not to succeed, since more concrete concerns with such visible problems as consumer and third-party health and safety have failed to motivate institutional change and code effectiveness. Those institutional barriers that have so far prohibited the adoption of a model code on a more limited basis, will continue to create barriers for the implementation of ASHRAE 90 or allow it to be implemented only in cannibalized form. These problems could be moderated with financial or economic arguments.

Experience has shown that, because of limited resources, manpower, and commitment, enforcement of state codes is weak. ADL concludes that a combination of financial incentives, probably built into the utility rate structure and tied to the implementation of energy-conserving construction methods, and of penalties aimed at the energy user to achieve the same results, must be actively considered if energy conservation in building design is truly to be achieved on a widespread basis. An alternative, not investigated here, is to encourage long-term financing institutions to demand energy efficient structures.

7. *Impact on Building Habitability*

The principal impact of ASHRAE 90 on the health, safety, and welfare of building occupants will result from reduced ventilation and infiltration called for in the standard. Reduced humidity in winter will lead to some discomfort, but with the exception of certain medical facilities, no health hazard would result.

The standard is likely to increase greatly the importance of indoor air pollution sources, and to result in excessively increased exposures of nonsmokers to cigarette smoke particles, increased complaints about odors, and demands for separate smoking and nonsmoking areas. Additional similar problems are expected to arise under ASHRAE 90, though insufficient data are available to permit quantitative evaluation of these problems at this time.

CHAPTER II

BACKGROUND AND APPROACH TO THE APPLICATION OF ASHRAE 90

A. INTRODUCTION

In order to establish a representative data base upon which to evaluate the energy and economic implications of ASHRAE 90, three basic decisions were necessary:

1) Choice of those specific cities which best represent the nation's climatic variations, and around which the computer simulation effort can take place;

2) Selection of those building types which best represent the type of new construction covered by ASHRAE 90, and

3) The interpretation and actual application of the standard itself on each building type in each location.

The purpose of this chapter is to discuss the methodology used in making the above decisions. However, preceding this, and before discussing the results of the study, it would be useful to briefly review the industry conditions regarding energy conservation in buildings under which ASHRAE 90 has developed.

B. THE ATMOSPHERE FOR ENERGY CONSERVATION IN BUILDINGS

To say that the derivation of ASHRAE 90 has been difficult, would be an understatement. In January, 1975, Mr. Jack Tumilty, Chairman of the ASHRAE committee designated to develop the standard, estimated that over 50,000 written comments were submitted to the committee in response to the first draft of the document. He further estimated that the second, and last draft, issued for open review represented an estimated 1,000,000 man hours of voluntary effort on the part of approximately 100 individuals up to that time. This high level of effort on behalf of both the committee and the reviewers continued until the final document was approved in late 1975.

The development of any document such as ASHRAE 90 in the "post-embargo" era of energy awareness must accommodate certain established economic and institutional considerations embedded within the construction industry. The extended controversy mentioned above was the price paid by the committee in order to meet and resolve these considerations. In particular, ASHRAE 90's development was confronted with some major problems, including the following:

- There has been, and continues to be, considerable disagreement within the HVA/C design industry as to how energy conservation techniques can best be devised and implemented for new construction (e.g., component performance standards versus energy budgets).

- No conclusive data has yet been offered indicating that a single generalized energy conservation standard will have similar effects across all building types, much less different locations.
- Any trend towards energy conservation will affect the inherent economic structure of the construction industry, which historically has been highly sensitive to initial costs, and as such, has led to the design, construction, and management of relatively inefficient structures.
- Various factions within ASHRAE, each representing different self-interests, led to the existence of on-going controversy. Opinions have been expressed accusing the commercial interests of the industry of having instituted a major effort to influence the proposed standard. Likewise, there were accusations that design engineers, code authorities, and building owners have had too little input.
- Finally, there existed an unproven suspicion that ASHRAE 90 would pose an additional burden on all participants within the construction sector: higher first costs for owners, more required analyses from engineers, more costly equipment from manufacturers, and possibly less comfort for occupants.

Even prior to ASHRAE's efforts, individual state legislatures were generally stepping up their activities regarding energy conservation in all sectors. This had been accelerated by the oil embargo of 1973/74. Energy conservation in buildings was identified early as a major and identifiable target for action, and it was this initial interest by the states that encouraged NCSBCS to originally request NBS to develop energy conservation design and evaluation criteria which could be used as the framework of a voluntary consensus standard for adoption by state and local governments.

Present interest and authority in the regulation of building energy utilization varies from state to state. As such, the extent to which ASHRAE 90, or any similar voluntary consensus document, will be adopted varies and will in all probability never cover the entire domestic construction industry.

In response to the interest shown in state activity in this area, various surveys have been made to determine the extent to which states have adopted laws granting statewide authority to regulate energy usage in buildings. As an example on how quickly this is changing, in January, 1975, 30 states had taken some positive action in this field. Six months later this had increased to 38 states.

In June, 1975, Mr. Kenneth Henke, then Chairman of NCSBCS, addressed ASHRAE's Annual Meeting in Boston concerning the status of state legislative activity. Using data obtained in a recent NBS survey,[1] he subdivided the states into six groups depending upon the extent to which they have adopted energy conservation laws. These are shown in Table II-1, and may be summarized as follows:

Group	Number of States
States with mandatory laws	18
States with voluntary laws	2
States with bills pending	9
States in the study or planning stage	6
States that had bills in legislation, but were killed	3
States in which no action is taking place	12
TOTAL	50

The legislation already enacted takes different forms in different states. Most covers both residential and commercial buildings, although some focuses on only one or the other, some electric heat only, etc. Five states have adopted their own building energy regulations, two more have regulations of a limited nature, and three states were in the process of developing their own regulations. Furthermore, the survey indicates that most of these same states would consider accepting a subsequent nationally-recognized standard as the basis for their regulations in the future.

The remainder of the states with existing authority to adopt building energy standards but which have not done so as yet, indicated that they plan to wait for a national consensus standard such as ASHRAE 90. Those states without present authority to regulate building energy use also indicated interest in a nationally-recognized standard as their basis for seeking such authority, or for recommending to local governments for their uses.

In reality, ASHRAE 90 while being the first and most prominent standard for energy conservation in new buildings, has received only the official endorsement of ASHRAE. However, there was broad engineering representation in the development of the standard. In order to become a nationally-recognized standard (and therefore acceptable to many of the interested states), it must be processed through the American National Standards Institute (ANSI). ASHRAE intends to submit Standard 90-75 to ANSI for approval sometime around mid-1976.

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[1] Robert M. Eisenhard, Building Energy Authority and Regulations Survey: State Activity (Washington, D. C.: U.S. Department of Commerce, National Bureau of Standards, NBSIR 75-747), Preliminary Report, June 1975.

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TABLE II-1

STATUS OF STATE AUTHORITY IN REGULATING BUILDING ENERGY USAGE, June 1975

States with Mandatory Laws (18)

California*
Colorado*
Connecticut
Idaho
Iowa**
Maine*
Massachusetts**
Michigan*
Minnesota*
Montana**
New Mexico**
North Carolina*
Ohio*
Oregon**
Rhode Island**
Virginia**
Washington
Wisconsin*

States with Voluntary Laws (2)

Georgia
Maryland**

States with Bills Pending (13)

Alabama
Arizona
Florida
Illinois
Indiana
New Jersey
New York
West Virginia
Wyoming

States in the Study or Planning Stages (6)

Kansas
Nevada
Pennsylvania
South Carolina
Tennessee
Texas

States with Legislation Defeated (3)

New Hampshire
Utah
Vermont

States with No Legislative Activity (12)

Alaska
Arkansas
Delaware
Hawaii
Kentucky
Louisiana
Mississippi
Missouri
Nebraska
North Dakota
Oklahoma
South Dakota

*Developed own standard; often based on ASHRAE 90P.

**Will probably adopt ASHRAE 90.

SOURCE: Paper present at ASHRAE's Annual Meeting, Boston, by Kenneth Henke, Chairman, NCSBCS, June 1975; based upon an NBS survey.

In review, it appears that ASHRAE 90 could subsequently be adopted by a majority of states, particularly after it has gone through the ANSI review process, which may take from several months to over a year to complete. For those states which have already forged ahead in developing their own regulations, their documents, in many cases, were based upon either the original NBS publication or a previous draft of ASHRAE 90, and as such, probably have energy and economic implications similar to those of ASHRAE 90.

C. SELECTION OF GEOGRAPHICAL LOCATION

Geographical location will have a major effect on building energy demands for space heating and cooling. From previous studies, it has been shown that space heating is the overriding factor in energy demand within the construction sector. As such, the variation in space heating requirements (as measured in degree days) became the prime criteria in selecting geographical locations for the impact study. In order to evaluate ASHRAE 90's effect on energy consumption using computer simulation techniques, specific geographical locations had to be selected which were representative of the nation's climatic variations.

To best describe the heating requirements within each of the four Census regions, a weighted average number of annual heating degree days was derived which represented the "center of gravity" for heating within each region. Using data compiled by the U.S. Weather Bureau, and weighting it by metropolitan population centers, ADL derived the average number of annual degree days within each state. Once these weighted averages were determined, they were multiplied by the number of housing units in the state, and the products totaled by region. The total of the products were then divided by the number of units within each region to get a weighted average of the heating degree days within the region.

Once the weighted average degree day was calculated, five to ten candidate cities were selected within each region whose annual heating degree day load was close to the regional average. For each candidate location, the ASHRAE recommended design dry bulb and wet bulb outdoor design temperatures were compared to determine which single location was most "representative" of the cooling requirements of that region. This criterion was admittedly subjective and although the methodology is somewhat unsophisticated, the energy usage estimates are believed to be reasonably representative for each region as a whole.

A second exercise in the application of ASHRAE 90 was a brief investigation into how effective a nondepletable energy system (in this case, solar energy) would be in reducing the conventional building's demand for utilities. The solar energy system analysis was based upon ADL's rather sophisticated in-house computer model which utilizes actual hourly insolation data. Inasmuch as hourly data is available from a relatively few number of U.S. Weather Bureau locations, some consideration in the selection of the representative cities in each of the regions was given to the availability of solar weather data. In three of the four regions, representative cities were selected for which coincident hourly insolation data were available. However, in the South region, hourly solar data was not available for Atlanta so Nashville was assumed as a "proxy" determining the effectiveness of a solar system. This substitution does not greatly affect the results.

Table II-2 lists the weighted average annual heating degree days for each region along with the city selected for use in the analysis.

D. SELECTION OF THE PROTOTYPICAL BUILDINGS

That segment of the construction industry affected by ASHRAE 90 can be considered in terms of a residential and nonresidential sector. In the residential sector, the majority of the dwellings constructed within the United States in any given year are detached single-family residences. The remaining volume is referred to as multi-family and consists of low-density housing (2-4 units), low-rise apartments (e.g., garden apartments, town houses, etc.) and high-rise apartments. Structures of three stories or less (i.e., low-rise) typically account for 75-80% of the multi-family units erected, with high-rise construction (i.e., greater than seven stories) responsible for the remainder. On the basis of this volume, two residential building types were selected for analysis: a single-family house and a low-rise apartment building.

Concerning the nonresidential sector, McGraw Hill's F. W. Dodge Construction Division in reporting construction activity shows 16 major classifications of building types. On the basis of the comparative square footage of new floor area, a representative building type was selected for each of the three largest Dodge classifications: a single-story retail store (store and mercantile), a low-rise office building (offices and banks), and a single-story school (educational).

The remaining buildings were eliminated from consideration due to both funding and market reasons.[2] Although commercial and industrial warehouse construction is significant in its annual volume, only a small percentage of this is comfort conditioned. Garages and auto service buildings as well as amusement/social/recreational structures were too small an annual volume to warrant detailed investigation. In the institutional area, laboratories, libraries/museums, dormitories, and religious buildings account for an insignificant percentage of the construction volume. The category encompassing miscellaneous nonresidential buildings was also eliminated from consideration.

It was further felt that the suburban school building chosen was also indicative of college and university buildings. Likewise, ADL assumed that government buildings were similar to the commercial office building already selected.

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[2] Building types which offer significant annual construction volumes and which might be the target of additional analysis under ASHRAE 90 include hospitals and health, hotels and motels, and light industrial.

TABLE II-2

REPRESENTATIVE LOCATIONS SELECTED FOR COMPUTER ANALYSIS OF PROTOTYPICAL BUILDINGS

	Weighted Average Annual Heating Degree Days	Location Selected			
		City	Degree Days	Summer Design Conditions	
				db	wb
Northeast	5,470	New York (Airport)	5,219	87°	76°
North Central	6,345	Omaha	6,612	94°	78°
South	2,795	Atlanta	2,961	92°	77°
West	3,515	Albuquerque	4,348	94°	65°

SOURCE: Arthur D. Little, Inc.

TABLE II-2

PRESENTATIVE LOCATIONS SELECTED FOR COMPUTER ANALYSIS OF PROTOTYPICAL BUILDINGS

Weighted Average Annual Heating Degree Days	Location Selected				Data Used for Solar Energy Analysis
	City	Degree Days	Summer Design Conditions		
			db	wb	
5,470	New York (Airport)	5,219	87°	76°	New York (City)
6,345	Omaha	6,612	94°	78°	Omaha
2,795	Atlanta	2,961	92°	77°	Nashville
3,515	Albuquerque	4,348	94°	65°	Albuquerque

A review of the building types selected shows a spectrum of energy demand for comfort conditioning which includes both intensive daytime usage (retail stores, office buildings, school) and continuous 24-hour demand (residential). Note should be taken that the buildings selected are prototypical and do not represent the average building within each region. In reality, there is an extreme diversity in the nonresidential category, and there is no statistically representative structure for any building type.

Once the geographical location and building types had been selected, each prototypical building had to be described in terms of its area, height, configuration, exterior roof and wall construction, internal loads, usage, and HVA/C system. Decisions on these variables were based upon knowledge of the construction industry and upon previously completed telephone interviews by ADL with local architects in each of the four regions investigated.

Assembling this information, it was evident that certain prototypical buildings showed little, if any, variance between regions. Thus, for purposes of simplification, similar building dimensions, descriptions were assumed for all but the single-family residence. Major regional differences centered around wall materials, insulation, and percent fenestration. For the single-family residence, three prototypical units were selected; exterior wall construction, floor area, and configuration varied. The building designs selected are a reasonable representation of current construction practices regarding thermal integrity, and are neither indicative of the lower insulation standards common in the not too distant past (e.g., 1970), nor of the higher standards obtainable if alternative energy conservation practices are followed.

Table II-3 indicates which prototypical buildings were selected for which geographical regions, while Table II-4 summarizes the characteristics of each of the prototypical buildings.

The single-family homes (SF_1, SF_2, and SF_3) were either of lapped wood siding, brick, or stucco exteriors, depending upon geographical location. Sizes ranged from 1600 to 1700 square feet in area, and all are single-story ranch style with sloped roofs. The amount of insulation assumed was based on discussions with several developers and home builders, and may or may not meet FHA insulation standards for Federally-assisted residential construction. (The majority of new housing starts are not undertaken by large national developers nor are they financed under government programs.) In those buildings shown, wall insulation is roughly similar to either Standard R-7 or R-11, and roof insulation is generally similar to Standard R-11. Window area was assumed to be 15% for all walls.

The low-rise, multi-family buildings (MFL_1, and MFL_2) are similar to those constructed by small apartment developers featuring garden apartments, townhouses, etc. The two-story prototypical building consists of 20 apartments of 900 square feet each with the units double-loaded

TABLE II-3

BUILDING TYPE/LOCATION MATRIX

	Northeast	North Central	Sout
Single-Family Residence	SF_1	SF_1	SF_2
Low-Rise Apartment Building	MFL_1	MFL_1	MFL_2
Office Building	OB_1	OB_1	OB_2
Retail Store	RS_1	RS_1	RS_1
School Building	SCH_1	SCH_1	SCH_2

TABLE II-3

BUILDING TYPE/LOCATION MATRIX

	Northeast	North Central	South	West
	SF_1	SF_1	SF_2	SF_3
ling	MFL_1	MFL_1	MFL_2	MFL_2
	OB_1	OB_1	OB_2	OB_2
	RS_1	RS_1	RS_1	RS_1
	SCH_1	SCH_1	SCH_2	SCH_2

TABLE II-4

DESCRIPTION OF CONVENTIONAL BUILDINGS USED IN THE ANALYSIS

Building	Total Area (Sq. Ft.)	Configuration (Ft.)	Number of Floors	Total Height (Ft.)	Exterior Wall Construction	Fenestration	Roof Const
SF_1	1,600	32' x 50'	1, unheated basement	10	½" lapped wood siding; ½" plywood sheathing; 2" x 4" stud framing (16" o.c.); 3½" fiberglass insulation; ½" Gypsum wallboard.	Single-strength sheet; 15% all walls.	Asphalt shingle sheathing; 3½" lation; ½" Gyps ventilated atti 3 in. 12.
SF_2	1,675	33'6" x 50'	1, slab on grade	10	4" common brick, 2" x 4" stud framing (16" o.c.); 3½" fiberglass insulation; ½" Gypsum wallboard.	Single-strength sheet; 15% all walls.	Asphalt shingle sheathing; 6" f sulation; ½" Gy ventilated atti 3 in. 12.
SF_3	1,705	30' x 50'	1, crawl space	10	3/4" stucco; 8" concrete block; 3½" fiberglass insulation; light framing; ½" Gypsum wallboard.	Single-strength sheet; 15% all walls.	Asphalt shingle sheathing; 3½" lation; ½" Gyps ventilated atti 3 in. 12.
MFL_1	18,000	50' x 180'	2, heated basement	24	½" lapped wood siding; ½" plywood sheathing; 2" x 4" stud framing (16" o.c.); 2¼" fiberglass insulation; ½" Gypsum wallboard.	Single-strength sheet; 30% sidewalls; 0% end walls.	Asphalt shingle sheathing; 3½" lation; ½" Gyps ventilated atti 3 in. 12.
MFL_2	18,000	50' x 180'	2, slab on grade	24	4" common brick; ½" plywood sheathing; light framing; no insulation; ½" Gypsum wallboard.	Single-strength sheet; 30% sidewalls; 0% end walls.	Asphalt shingle sheathing; 3" f lation; ½" Gyps ventilated atti 3 in. 12.
OB_1	40,000	90' x 150'	3	36	6" precast concrete panels.	¼" plate; 30% all walls.	4-ply built-up gravel; 2" rigi steel decking; ½" softboard.
OB_2	40,000	90' x 150'	3	36	1" insulated sandwich panel with aluminum mullions; structural steel framing.	¼" plate; 50% all walls.	Metal deck; 4" roofing; struct framing; ½" sof ceiling.

TABLE II-4

ESCRIPTION OF CONVENTIONAL BUILDINGS USED IN THE ANALYSIS

t	Exterior Wall Construction	Fenestration	Roof Construction
	½" lapped wood siding; ½" plywood sheathing; 2" x 4" stud framing (16" o.c.); 3½" fiberglass insulation; ½" Gypsum wallboard.	Single-strength sheet; 15% all walls.	Asphalt shingles; ½" plywood sheathing; 3½" fiberglass insulation; ½" Gypsum wallboard; ventilated attic; roof slope: 3 in. 12.
	4" common brick, 2" x 4" stud framing (16" o.c.); 3½" fiberglass insulation; ½" Gypsum wallboard.	Single-strength sheet; 15% all walls.	Asphalt shingles; ½" plywood sheathing; 6" fiberglass insulation; ½" Gypsum wallboard; ventilated attic; roof slope: 3 in. 12.
	3/4" stucco; 8" concrete block; 3½" fiberglass insulation; light framing; ½" Gypsum wallboard.	Single-strength sheet; 15% all walls.	Asphalt shingles; ½" plywood sheathing; 3½" fiberglass insulation; ½" Gypsum wallboard; ventilated attic; roof slope: 3 in. 12.
	½" lapped wood siding; ½" plywood sheathing; 2" x 4" stud framing (16" o.c.); 2¼" fiberglass insulation; ½" Gypsum wallboard.	Single-strength sheet; 30% sidewalls; 0% end walls.	Asphalt shingles; ½" plywood sheathing; 3½" fiberglass insulation; ½" Gypsum wallboard; ventilated attic; roof slope: 3 in. 12.
	4" common brick; ½" plywood sheathing; light framing; no insulation; ½" Gypsum wallboard.	Single-strength sheet; 30% sidewalls; 0% end walls.	Asphalt shingles; ½" plywood sheathing; 3" fiberglass insulation; ½" Gypsum wallboard; ventilated attic; roof slope: 3 in. 12.
	6" precast concrete panels.	¼" plate; 30% all walls.	4-ply built-up roofing with gravel; 2" rigid insulation; steel decking; open web joists; ½" softboard.
	1" insulated sandwich panel with aluminum mullions; structural steel framing.	¼" plate; 50% all walls.	Metal deck; 4" poured concrete roofing; structural steel framing; ½" softwood hung ceiling.

TABLE II-4

DESCRIPTION OF CONVENTIONAL BUILDINGS USED IN THE ANALYSIS

Building	Total Area (Sq. Ft.)	Configuration (Ft.)	Number of Floors	Total Height (Ft.)	Exterior Wall Construction	Fenestration	Roof Co
RS_1	32,400	180' x 180'	1	15	12" concrete block, painted both sides.	¼" plate; 60% South wall; 0% all other walls.	4-ply built- gravel; 2" r steel deckin ½" softboard
S_1	40,000	100' x 400'	1	14	4" common brick, 1" fiberglass insulation, 4" concrete block.	Single-strength sheet; 20% all walls.	4-ply built- gravel; 2" r steel deckin ½" softboard
S_2	40,000	100' x 400'	1	14	4" common brick, no insulation, 4" concrete block.	Single-strength sheet; 20% all walls.	4-ply built- gravel; 1" r 4" concrete steel framin

TABLE II-4

DESCRIPTION OF CONVENTIONAL BUILDINGS USED IN THE ANALYSIS

of e	Total Height (Ft.)	Exterior Wall Construction	Fenestration	Roof Construction
	15	12" concrete block, painted both sides.	¼" plate; 60% South wall; 0% all other walls.	4-ply built-up roofing with gravel; 2" rigid insulation; steel decking; open web joists; ½" softboard.
	14	4" common brick, 1" fiberglass insulation, 4" concrete block.	Single-strength sheet; 20% all walls.	4-ply built-up roofing with gravel; 2" rigid insulation; steel decking; open-web joists; ½" softboard.
	14	4" common brick, no insulation, 4" concrete block.	Single-strength sheet; 20% all walls.	4-ply built-up roofing with gravel; 1" rigid insulation; 4" concrete plank; structural steel framing; ½" softboard.

around a central corridor. Exterior wall construction is either frame, stucco, or common brick with or without insulation. Window area was assumed to be 30% along the longer axis of the building to account for such items as sliding-glass door patios or balconies.

The office buildings (OB_1 and OB_2), are three stories high and 40,000 square feet and are typical of the suburban office park concept. One structure is of heavy masonry construction, consisting of 6" precast concrete walls, with 30% fenestration. The other building is of curtain wall construction utilizing insulated sandwich panels, aluminum mullions, and having a window area of 50%.

The retail store (RS_1) is similar to the small suburban shopping center of the discount store variety, i.e., single-story, masonry construction, and in the range of 30,000 to 40,000 square feet. Such structures are often designed and constructed by large chain stores, and consist of no wall insulation other than painted concrete block. Windows are generally limited only to the store front.

The school (S_1) is representative of suburban single-story structures with enrollments on the order of 400 to 500 students. It is of common brick over concrete block with or without masonry wall insulation (R-5). Fenestration was assumed to be 20% of all wall areas.

E. DESCRIPTION OF THE STANDARD

ASHRAE 90 itself consists of eleven "sections," similar to chapters. Sections 1 through 3 establish the purpose, intended scope, and definitions used in the document. Sections 4 through 9 are intended to be used collectively in a component performance approach with a few prescriptive requirements. Section 10 permits a systems analysis approach to be used as an alternative to the prescriptive/performance approach. Section 11 sets requirements for buildings utilizing solar, wind, or other nondepleting energy sources as yet a third approach to conserving energy.

At one time during the development of the standard, an additional chapter, Section 12 (Annual Fuel and Energy Resource Determination), was included. Section 12 required the determination of a building's energy consumption based on source energy, rather than on energy supplied at the building boundary. After considerable discussion, Section 12 was dropped from ASHRAE 90, but is being reviewed for possible inclusion into the standard at a later date. ADL's investigation focused on the current edition of ASHRAE 90, which does not include any requirements for source energy analysis.

While it was not within ADL's scope to undertake a technical evaluation of the document, it is important to point out the changes in conventional construction practices which will probably be required to meet the standard. Table II-5 briefly lists selected sections, notes their

TABLE II-5

SELECTED REMARKS ON ASHRAE 90-75

Section	Effects on Conventional Construction Practice	Industry Secto
EXTERIOR ENVELOPE (4.0)	*Implications: Places minimum thermal performance criteria on external building envelopes; will result in basic changes in glass area and wall materials; more A/E design time required for trial-and-error solutions.*	
4.2.1	Requirements are different for residential and non-residential construction; suggests major increased in insulation and/or decreased fenestration.	Commodity buil window fabrica suppliers, ins
4.2.5	Sets specific indoor and outdoor design temperatures where they had previously been left to the designer.	All building m suppliers; HVA suppliers
4.3.2.1	May render residential with no insulation obsolete; U-factors in agreement with HUD's MPS standards; could require double glazing in some locations to retain conventional window areas.	Insulation sup window fabrica glass supplier
4.3.2.2	Considerable improvement over conventional roof construction.	Insulation sup residential bu
4.3.2.3&4	Will require some floor insulation on most, if not all, new construction; considerable improvement over conventional construction.	Insulation sup residential bu
4.4.2.1&2	Will result in major change in commercial wall construction; uninsulated light construction may not comply.	All building m suppliers, insu
4.4.2.4	Perimeter insulation now required; seldom used in past.	Insulation sup
4.4.3	Both heating and cooling conditions must meet the standard; trial-and-error approach might be required.	All building m suppliers, insu suppliers, A/E
4.5.3	Generally requires better caulking and weatherstripping	Residential bui window fabricat

TABLE II-5

SELECTED REMARKS ON ASHRAE 90-75

Effects on Conventional Construction Practice	Industry Sectors Affected
Implications: Places minimum thermal performance criteria on external building envelopes; will result in basic changes in glass area and wall materials; more A/E design time required for trial-and-error solutions.	
Requirements are different for residential and non-residential construction; suggests major increased in insulation and/or decreased fenestration.	Commodity building materials, window fabricators, glass suppliers, insulation suppliers
Sets specific indoor and outdoor design temperatures where they had previously been left to the designer.	All building materials suppliers; HVA/C equipment suppliers
May render residential with no insulation obsolete; U-factors in agreement with HUD's MPS standards; could require double glazing in some locations to retain conventional window areas.	Insulation suppliers, window fabricators, glass suppliers
Considerable improvement over conventional roof construction.	Insulation suppliers, residential builders
Will require some floor insulation on most, if not all, new construction; considerable improvement over conventional construction.	Insulation suppliers, residential builders
Will result in major change in commercial wall construction; uninsulated light construction may not comply.	All building materials suppliers, insulation suppliers
Perimeter insulation now required; seldom used in past.	Insulation suppliers
Both heating and cooling conditions must meet the standard; trial-and-error approach might be required.	All building materials suppliers, insulation suppliers, A/E designers
Generally requires better caulking and weatherstripping	Residential builders, window fabricators

TABLE II-5

SELECTED REMARKS ON ASHRAE 90-75 (Continued)

Section	Effects on Conventional Construction Practice	Industry Sectors Aff
HVA/C SYSTEMS (5.0)	*Implications: Decrease in ventilation rates, along with decreased infiltration due to a tighter exterior skin, may have a negative effect or indoor air quality.*	
5.3.2.3	Reductions in ventilation rates are significant; anticipate major reduction in heating and cooling equipment capacity.	HVA/C equipment supp
5.4.1	Allows for greater range of temperature set points; "dead band" created, within which no heating nor cooling will be supplied.	HVA/C equipment supp mechanical controls suppliers
5.4.2	Not all building types utilize humidity control; reducing humidity requirements decreases system capacity; does not require humidity control, only that it be used differently.	Mechanical controls HVA/C equipment supp
5.4.3.1	Will require where most residences had only single zone.	Mechanical control
5.5	Controls delivered air temperature; prevents simultaneous heating and cooling; increases control requirements over conventional construction.	Mechanical control HVA/C equipment supp
5.5.7	Will require more design effort to determine how loads will vary between comparative zones.	A/E designers
5.6	Requires economizer cycle; most, but not all, large projects employ this already.	Mechanical control HVA/C equipment supp
5.8	May discourage high pressure distribution systems in some commercial situations.	Mechanical control HVA/C equipment supp
5.10	Typically not required until field problems arise.	A/E designers; buil tractors; insulatio
5.11	Requires return duct typically in plenums only 10-20 of time plenums typically not insulated.	Insulation supplier building contractor

TABLE II-5

SELECTED REMARKS ON ASHRAE 90-75 (Continued)

cts on Conventional Construction Practice	Industry Sectors Affected
lications: Decrease in ventilation rates, along with decreased infiltration due to a tighter exterior skin, may have a negative effect or indoor air quality.	
ctions in ventilation rates are significant; cipate major reduction in heating and cooling pment capacity.	HVA/C equipment suppliers
ws for greater range of temperature set points; "dead " created, within which no heating nor cooling will upplied.	HVA/C equipment suppliers, mechanical controls suppliers
all building types utilize humidity control; reducing dity requirements decreases system capacity; does require humidity control, only that it be used erently.	Mechanical controls suppliers, HVA/C equipment suppliers
require where most residences had only single .	Mechanical control suppliers
rols delivered air temperature; prevents simul-ous heating and cooling; increases control require-s over conventional construction.	Mechanical control suppliers, HVA/C equipment suppliers
require more design effort to determine how loads vary between comparative zones.	A/E designers
ires economizer cycle; most, but not all, large ects employ this already.	Mechanical control suppliers, HVA/C equipment suppliers
discourage high pressure distribution systems in commercial situations.	Mechanical control suppliers, HVA/C equipment suppliers
cally not required until field problems arise.	A/E designers; building contractors; insulation suppliers
ires return duct typically in plenums only 10-20 of plenums typically not insulated.	Insulation suppliers, building contractors

TABLE II-5

SELECTED REMARKS ON ASHRAE 90-75 (Continued)

Section	Effects on Conventional Construction Practice	Industry Sectors
HVA/C EQUIPMENT (6.0)	*Implications: Minimum COP's will require widespread equipment testing and compliance; equipment may now be bought on performance, not on cost.*	
6.2	COP's of conventional systems vary considerably; do not anticipate this will preclude any good-quality existing equipment from being sold. Manufacturers will have to provide partial load efficiency data for partial load operating conditions; such data typically unavailable now.	HVA/C equipment s
6.9	Undertaken by design A/E firms only on an extra fee basis.	A/E designers
SERVICE WATER HEATING (7.0)	*Implications: Encourages better insulated equipment.*	
7.3.1.1	Current equipment to meet even 1977 requirements.	Water heater suppl
7.3.1.2	Equipment must be improved to meet 1977 requirements.	Water heater suppl
7.4 & 7.5	Controls typically attached, but may be difficult to reach.	Water heater suppl
7.7.1	Conventional shower heads 6 to 12 gpm.	Hardware supplier
ELECTRICAL SYSTEMS (8.0)	*Implications: No impact on designers already using NEC.*	
8.2	Power factor correction must be provided, should result in better equipment selection.	Electrical equipm suppliers
8.4	Feeder lines may increase slightly.	Electrical equipm
LIGHTING POWER BUDGET (9.0)	*Implications: Requires designers to follow IES guidelines more closely; eliminates temptation to misuse recommendations.*	

TABLE II-5

SELECTED REMARKS ON ASHRAE 90-75 (Continued)

cts on Conventional Construction Practice	Industry Sectors Affected
ications: *Minimum COP's will require widespread equipment testing and compliance; equipment may now be bought on performance, not on cost.*	
s of conventional systems vary considerably; do not cipate this will preclude any good-quality existing pment from being sold. Manufacturers will have to ide partial load efficiency data for partial load ating conditions; such data typically unavailable now.	HVA/C equipment suppliers
rtaken by design A/E firms only on an extra fee basis.	A/E designers
ications: *Encourages better insulated equipment.*	
ent equipment to meet even 1977 requirements.	Water heater suppliers
pment must be improved to meet 1977 requirements.	Water heater suppliers
rols typically attached, but may be difficult to h.	Water heater suppliers
entional shower heads 6 to 12 gpm.	Hardware suppliers
ications: *No impact on designers already using NEC.*	
r factor correction must be provided, should result etter equipment selection.	Electrical equipment suppliers
er lines may increase slightly.	Electrical equipment suppliers
ications: *Requires designers to follow IES guidelines more closely; eliminates temptation to misuse recommendations.*	

TABLE II-5

SELECTED REMARKS ON ASHRAE 90-75 (Continued)

Section	Effects on Conventional Construction Practice	Industry Se
SYSTEMS ANALYSIS (10.0)	*Implications:* *Requires two designs; increased design times would almost insure use of computer simulation programs on large projects.*	
10.4	Never required under any previous circumstances.	A/E designe
NONDEPLETING ENERGY SOURCES (11.0)	*Implications:* *Provides for, but does not encourage, the use of alternative energy sources to reduce energy consumption in buildings.*	

TABLE II-5

SELECTED REMARKS ON ASHRAE 90-75 (Continued)

Effects on Conventional Construction Practice	Industry Sectors Affecte
Implications: *Requires two designs; increased design times would almost insure use of computer simulation programs on large projects.*	
Never required under any previous circumstances.	A/E designers
Implications: *Provides for, but does not encourage, the use of alternative energy sources to reduce energy consumption in buildings.*	

implications, comments on their effect, and indicates which industry sectors will be economically affected due to their implementation.

F. APPLICATION OF ASHRAE 90 TO THE PROTOTYPICAL BUILDINGS

Perhaps the most important exercise in the entire project was the interpretation of the standard and its application to the prototypical buildings. Not only were the characteristics of the conventional building critical in selecting what had to be modified, but where there was a choice among several alternatives, it had to be determined how the building was to be modified.

The approach in modifying the conventional buildings was based upon professional design judgment as to what the architect/engineer would be most likely to do, and what the client would be most likely to permit aesthetically. In applying the standard, recommended numerical values listed in the standard were assumed to be targets, and as such, only the barest minimum of modification was undertaken to meet the targets. The philosophy was to meet, but not purposely exceed the standard, as it was felt that the client and design community will not choose to adopt major modifications in either building appearance or system performance. Such decisions are typically not controlled by life-cycle economics.

Using ASHRAE 90 on a case-by-case basis, changes were made in indoor and outdoor design conditions, exterior wall and roof heat transmittance, lighting levels, window area and type, etc. For each modification, actual materials and/or different HVA/C equipment were selected which later formed the basis for determining the impact on the selected industry subsectors.

Tables II-6 through II-10 summarize the major physical changes made in each building type for each region. For reference purposes, the appropriate section of ASHRAE 90 is shown for each design parameter changed. Other critical assumptions may be summarized as follows:

- *Type of Fuel:* The same fuel was considered for both the conventional and ASHRAE 90 modified buildings, i.e., alternative fuel sources were not evaluated. The fuels selected for the various regions were predominant in these regions.

- *HVA/C Systems:* Systems selected for the various building types were as follows:

  Single Family - Hot air furnace with split system cooling, direct expansion (DX) coil. No economizer cycle, no humidification, no night setback.

TABLE II-6

SINGLE FAMILY RESIDENCE: SUMMARY OF CHANGES IN DESIGN PARAMETERS, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED PROT

Design Variable	Applicable Section of ASHRAE 90-75	Northeast Conv.	Northeast 90-75	North Central Conv.	North Central 90-75	South Conv.	South 90-75
Design Conditions:							
Summer Outdoor, °F DB/°F WB	4.2.5, 5.3.2.1, 5.3.2.2	91/77	87/76	97/79	94/78	95/78	92/77
Summer Indoor, °F DB/ %RH max		75/50	78/60	75/50	78/60	75/50	78/60
Winter Outdoor, °F DB		12	21	-12	-1	14	23
Winter Indoor, °F DB		75	72	75	72	75	72
Exterior Envelope:							
Glass Area (percent of gross wall area) North	4.3.2.1	15	15	15	14.4	15	15
East		15	15	15	14.4	15	15
South		15	15	15	14.4	15	15
West		15	15	15	14.4	15	15
Glass U (Btu/hr. ft.^{2} °F)		1.13	1.13	1.13	1.13	1.13	1.13
Wall U (Btu/hr. ft.^{2} °F)		0.087	0.063	0.087	0.063	0.087	0.087
Overall Wall "Uo" (Btu/hr. ft.^{2} °F)		0.24	0.22	0.24	0.21	0.24	0.24
Roof U (Btu/hr. ft.^{2} °F)	4.3.2.2	0.074	0.050	0.074	0.050	0.048	0.045
Floor Perimeter U (Btu/hr. ft.^{2} °F)	4.3.2.3, 4.3.2.4						
Lighting/Power (Watts/sq. ft.)	9.3, 9.4	1.0	0.8	1.0	0.8	1.0	0.8
Ventilation (cfm/sq. ft.)							
Infiltration (Air Change/hr.)	4.5.3, 5.3.2.4	1.0	0.93	1.0	0.93	1.0	0.93
Domestic Hot Water Temperature Rise (°F)	7.3	100	70	100	70	100	70

SOURCE: Kling-Lindquist, Inc., based on strict interpretation of ASHRAE 90-75.

TABLE II-6

MARY OF CHANGES IN DESIGN PARAMETERS, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED PROTOTYPICAL STRUCTURE

	Applicable Section of ASHRAE 90-75	Northeast		North Central		South		West	
		Conv.	90-75	Conv.	90-75	Conv.	90-75	Conv.	90-75
	4.2.5, 5.3.2.1, 5.3.2.2	91/77	87/76	97/79	94/78	95/78	92/77	96/66	94/65
		75/50	78/60	75/50	78/60	75/50	78/60	75/50	78/60
		12	21	-12	-1	14	23	6	17
		75	72	75	72	75	72	75	72
	4.3.2.1	15	15	15	14.4	15	15	15	14.8
		15	15	15	14.4	15	15	15	14.8
		15	15	15	14.4	15	15	15	14.8
		15	15	15	14.4	15	15	15	14.8
		1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
		0.087	0.063	0.087	0.063	0.087	0.087	0.087	0.087
F)		0.24	0.22	0.24	0.21	0.24	0.24	0.24	0.24
	4.3.2.2	0.074	0.050	0.074	0.050	0.048	0.045	0.048	0.045
F)	4.3.2.3, 4.3.2.4								
	9.3, 9.4	1.0	0.8	1.0	0.8	1.0	0.8	1.0	0.8
	4.5.3, 5.3.2.4	1.0	0.93	1.0	0.93	1.0	0.93	1.0	0.93
(°F)	7.3	100	70	100	70	100	70	100	70

d on strict interpretation of ASHRAE 90-75.

TABLE II-7

LOW-RISE APARTMENT BUILDING: SUMMARY OF CHANGES IN DESIGN PARAMETERS, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED PROTOT

Design Variable			Applicable Section of ASHRAE 90-75	Northeast		North Central		South	
				Conv.	90-75	Conv.	90-75	Conv.	90-75
Design Conditions:									
Summer	Outdoor, °F DB/°F WB		4.2.5, 5.3.2.1, 5.3.2.2	91/77	87/76	97/79	94/78	95/78	92/77
	Indoor, °F DB/ %RH max			75/50	78/60	75/50	78/60	75/50	78/60
Winter	Outdoor, °F DB			12	21	-12	-1	14	23
	Indoor, °F DB			75	72	75	72	75	72
Exterior Envelope:									
Glass Area (percent of gross wall area)		North	4.3.2.1	30	26.7	30	23.6	30	30
		East		0	0	0	0	0	0
		South		30	26.7	30	23.6	30	30
		West		0	0	0	0	0	0
Glass U (Btu/hr. ft.^{2} °F)				1.13	1.13	1.13	1.13	1.13	1.13
Wall U (Btu/hr. ft.^{2} °F)				0.093	0.068	0.093	0.068	0.370	0.072
Overall Wall "Uo" (Btu/hr. ft.^{2} °F)				0.340	0.290	0.340	0.264	0.550	0.334
Roof U (Btu/hr. ft.^{2} °F)			4.3.2.2	0.070	0.045	0.070	0.045	0.070	0.045
Floor Perimeter U (Btu/hr. ft.^{2} °F)			4.3.2.3, 4.3.2.4	0.20	0.16	0.20	0.14	0.41	0.21
Lighting/Power (Watts/sq. ft.)			9.3, 9.4	1	.8	1	.8	1	.8
Ventilation (cfm/sq. ft.)			5.3.2.3	.05	.025	.05	.025	.05	.025
Infiltration (Air Change/hr.)			4.5.3, 5.3.2.4	.5	.3	.5	.3	.5	.3
Domestic Hot Water Temperature Rise (°F)			7.3	100	70	100	70	100	70

SOURCE: Kling-Lindquist, Inc., based on strict interpretation of ASHRAE 90-75.

TABLE II-7

Y OF CHANGES IN DESIGN PARAMETERS, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED PROTOTYPICAL STRUCTURE

	Applicable Sectio of ASHRAE 90-75	Northeast		North Central		South		West	
		Conv.	90-75	Conv.	90-75	Conv.	90-75	Conv.	90-75
	4.2.5, 5.3.2.1, 5.3.2.2	91/77	87/76	97/79	94/78	95/78	92/77	96/66	94/65
		75/50	78/60	75/50	78/60	75/50	78/60	75/50	78/60
		12	21	-12	-1	14	23	6	17
		75	72	75	72	75	72	75	72
	4.3.2.1	30	26.7	30	23.6	30	30	30	28.2
		0	0	0	0	0	0	0	0
		30	26.7	30	23.6	30	30	30	28.2
		0	0	0	0	0	0	0	0
		1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
		0.093	0.068	0.093	0.068	0.370	0.072	0.370	0.072
		0.340	0.290	0.340	0.264	0.550	0.334	0.550	0.305
	4.3.2.2	0.070	0.045	0.070	0.045	0.070	0[illegible]	0.070	0.045
	4.3.2.3, 4.3.2.4	0.20	0.16	0.20	0.14	0.41	0.21	0.41	0.17
	9.3, 9.4	1	.8	1	.8	1	.8	1	.8
	5.3.2.3	.05	.025	.05	.025	.05	.025	.05	.025
	4.5.3, 5.3.2.4	.5	.3	.5	.3	.5	.3	.5	.3
F)	7.3	100	70	100	70	100	70	100	70

n strict interpretation of ASHRAE 90-75.

TABLE II-8

OFFICE BUILDING: SUMMARY OF CHANGES IN DESIGN PARAMETERS, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED PROTOTYPI

Design Variable			Applicable Section of ASHRAE 90-75	Northeast		North Central		South	
				Conv.	90-75	Conv.	90-75	Conv.	90-7
Design Conditions:									
Summer	Outdoor, °F DB/°F WB		4.2.5, 5.3.2.1, 5.3.2.2	91/77	87/76	97/79	94/78	95/78	92/7
	Indoor, °F DB/ %RH max			75/50	78/60	75/50	78/60	75/50	78/6
Winter	Outdoor, °F DB			12	21	-12	-1	14	23
	Indoor, °F DB			75/30	72/30	75/30	72/30	75/30	72/3
Exterior Envelope:									
Glass Area (percent of gross wall area)		North	4.4.2.1, 4.4.3.1	30	25	30	29	50	34.
		East		30	25	30	29	50	34.
		South		30	25	30	29	50	34.
		West		30	25	30	29	50	34.
Glass U (Btu/hr. ft.^{2} °F)				1.13	0.65	1.13	0.65	1.13	0.
Wall U (Btu/hr. ft.^{2} °F)				0.34	0.168	0.34	0.108	0.20	0.
Overall Wall "Uo" (Btu/hr. ft.^{2} °F)				0.580	0.290	0.580	0.265	0.665	0.
Roof U (Btu/hr. ft.^{2} °F)			4.4.2.2, 4.4.3.2	0.14	0.079	0.14	0.079	0.18	0.
Lighting/Power (Watts/sq. ft.)			9.3, 9.4	4.5	3.5	4.5	3.5	5.5	3.
Ventilation (cfm/sq. ft.)			5.3.2.3	.25	.148	.25	.148	.25	.
Infiltration (Air Change/hr.)			4.5.3, 5.3.2.4	.5	.3	.5	.3	.5	.
Domestic Hot Water Temperature Rise (°F)			7.3	100	70	100	70	100	70

SOURCE: Kling-Lindquist, Inc., based on strict interpretation of ASHRAE 90-75.

TABLE II-8

OF CHANGES IN DESIGN PARAMETERS, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED PROTOTYPICAL STRUCTURE

	Applicable Section of ASHRAE 90-75	Northeast		North Central		South		West	
		Conv.	90-75	Conv.	90-75	Conv.	90-75	Conv.	90-75
	4.2.5, 5.3.2.1, 5.3.2.2	91/77	87/76	97/79	94/78	95/78	92/77	96/66	94/65
		75/50	78/60	75/50	78/60	75/50	78/60	75/50	78/60
		12	21	-12	-1	14	23	6	17
		75/30	72/30	75/30	72/30	75/30	72/30	75/30	72/30
	4.4.2.1, 4.4.3.1	30	25	30	29	50	34.7	50	35.9
		30	25	30	29	50	34.7	50	35.9
		30	25	30	29	50	34.7	50	35.9
		30	25	30	29	50	34.7	50	35.9
		1.13	0.65	1.13	0.65	1.13	0.65	1.13	0.65
		0.34	0.168	0.34	0.108	0.20	0.113	0.20	0.113
F)		0.580	0.290	0.580	0.265	0.665	0.300	0.665	0.300
	4.4.2.2, 4.4.3.2	0.14	0.079	0.14	0.079	0.18	0.089	0.18	0.089
	9.3, 9.4	4.5	3.5	4.5	3.5	5.5	3.5	5.5	3.5
	5.3.2.3	.25	.148	.25	.148	.25	.148	.25	.148
	4.5.3, 5.3.2.4	.5	.3	.5	.3	.5	.3	.5	.3
(°F)	7.3	100	70	100	70	100	70	100	70

d on strict interpretation of ASHRAE 90-75.

TABLE II-9

RETAIL STORE: SUMMARY OF CHANGES IN DESIGN PARAMETERS, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED PROTO

Design Variable			Applicable Section of ASHRAE 90-75	Northeast		North Central		South	
				Conv.	90-75	Conv.	90-75	Conv.	90-75
Design Conditions:									
Summer	Outdoor, °F DB/°F WB		4.2.5, 5.3.2.1, 5.3.2.2	91/77	87/76	97/79	94/78	95/78	92/77
	Indoor, °F DB/ %RH max			75/50	78/60	75/50	78/60	75/50	78/60
Winter	Outdoor, °F DB			12	21	-12	-1	14	23
	Indoor, °F DB			75	72	75	72	75	72
Exterior Envelope:									
Glass Area (percent of gross wall area)		North	4.4.2.1, 4.4.3.1	0	0	0	0	0	0
		East		0	0	0	0	0	0
		South		60	60	60	52	60	60
		West		0	0	0	0	0	0
Glass U (Btu/hr. ft.^{2} °F)				1.13	1.13	1.13	1.13	1.13	1.13
Wall U (Btu/hr. ft.^{2} °F)				0.29	0.135	0.29	0.135	0.29	0.13
Overall Wall "Uo" (Btu/hr. ft.^{2} °F)				0.416	0.284	0.416	0.265	0.416	0.28
Roof U (Btu/hr. ft.^{2} °F)			4.4.2.2, 4.4.3.2	0.14	0.079	0.14	0.065	0.14	0.08
Floor Perimeter U (Btu/hr. ft.^{2} °F)			4.4.2.4	0.41	0.16	0.41	0.14	0.41	0.21
Lighting/Power (Watts/sq.ft.)			9.3, 9.4	6.0	4.5	6.0	4.5	6.0	4.5
Ventilation (cfm/sq. ft.)			5.3.2.3	.3	.216	.3	.216	.3	.21
Infiltration (Air Change/hr.)			4.5.3, 5.3.2.4	.5	.3	.5	.3	.5	.3
Domestic Hot Water Temperature Rise (°F)			7.3	100	70	100	70	100	70

SOURCE: Kling-Lindquist, Inc., based on strict interpretation of ASHRAE 90-75.

TABLE II-9

Y OF CHANGES IN DESIGN PARAMETERS, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED PROTOTYPICAL STRUCTURE

	Applicable Section of ASHRAE 90-75	Northeast		North Central		South		West	
		Conv.	90-75	Conv.	90-75	Conv.	90-75	Conv.	90-75
	4.2.5, 5.3.2.1, 5.3.2.2	91/77	87/76	97/79	94/78	95/78	92/77	96/66	94/65
		75/50	78/60	75/50	78/60	75/50	78/60	75/50	78/60
		12	21	-12	-1	14	23	6	17
		75	72	75	72	75	72	75	72
	4.4.2.1, 4.4.3.1	0	0	0	0	0	0	0	0
		0	0	0	0	0	0	0	0
		60	60	60	52	60	60	60	60
		0	0	0	0	0	0	0	0
		1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
		0.29	0.135	0.29	0.135	0.29	0.135	0.29	0.135
		0.416	0.284	0.416	0.265	0.416	0.284	0.416	0.284
	4.4.2.2, 4.4.3.2	0.14	0.079	0.14	0.065	0.14	0.089	0.14	0.089
	4.4.2.4	0.41	0.16	0.41	0.14	0.41	0.21	0.41	0.17
	9.3, 9.4	6.0	4.5	6.0	4.5	6.0	4.5	6.0	4.5
	5.3.2.3	.3	.216	.3	.216	.3	.216	.3	.216
	4.5.3, 5.3.2.4	.5	.3	.5	.3	.5	.3	.5	.3
(°F)	7.3	100	70	100	70	100	70	100	70

on strict interpretation of ASHRAE 90-75.

TABLE II-10

SCHOOL BUILDING: SUMMARY OF CHANGES IN DESIGN PARAMETERS, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED PROTOTYPICAL

Design Variable		Applicable Section of ASHRAE 90-75	Northeast		North Central		South	
			Conv.	90-75	Conv.	90-75	Conv.	90-75
Design Conditions:								
Summer	Outdoor, °F DB/°F WB	4.2.5, 5.3.2.1, 5.3.2.2	91/77	87/76	97/79	94/78	95/78	92/77
	Indoor, °F DB/ %RH max		75/50	78/60	75/50	78/60	75/50	78/60
Winter	Outdoor, °F DB		12	21	-12	-1	14	23
	Indoor, °F DB		75	72	75	72	75	72
Exterior Envelope:								
Glass Area (percent of gross wall area)	North	4.4.2.1, 4.4.31	20	18.5	20	16	20	20
	East		20	18.5	20	16	20	20
	South		20	18.5	20	16	20	20
	West		20	18.5	20	16	20	20
Glass U (Btu/hr. ft.^{2} °F)			1.13	1.13	1.13	1.13	1.13	1.13
Wall U (Btu/hr. ft.^{2} °F)			0.10	0.10	0.10	0.10	0.30	0.10
Overall Wall "Uo" (Btu/hr. ft.^{2} °F)			0.306	0.265	0.306	0.265	0.466	0.30
Roof U (Btu/hr. ft.^{2} °F)		4.4.2.2, 4.4.3.2	.14	.078	.14	.065	.23	.09
Lighting/Power (Watts/sq. ft.)		9.3, 9.4	4.0	3.5	4.0	3.5	4.0	3.5
Ventilation (cfm/sq. ft.)		5.3.2.3	.50	.25	.50	.25	.50	.25
Infiltration (Air Change/hr.)		4.5.3, 5.3.2.4	.50	.30	.50	.30	.50	.30
Domestic Hot Water Temperature Rise (°F)		7.3	100	70	100	70	100	70

SOURCE: Kling-Lindquist, Inc., based on strict interpretation of ASHRAE 90-75.

TABLE II-10

F CHANGES IN DESIGN PARAMETERS, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED PROTOTYPICAL STRUCTURE

	Applicable Section of ASHRAE 90-75	Northeast		North Central		South		West	
		Conv.	90-75	Conv.	90-75	Conv.	90-75	Conv.	90-75
	4.2.5, 5.3.2.1, 5.3.2.2	91/77	87/76	97/79	94/78	95/78	92/77	96/66	94/65
		75/50	78/60	75/50	78/60	75/50	78/60	75/50	78/60
		12	21	-12	-1	14	23	6	17
		75	72	75	72	75	72	75	72
	4.4.2.1, 4.4.31	20	18.5	20	16	20	20	20	20
		20	18.5	20	16	20	20	20	20
		20	18.5	20	16	20	20	20	20
		20	18.5	20	16	20	20	20	20
		1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
		0.10	0.10	0.10	0.10	0.30	0.10	0.30	0.10
F)		0.306	0.265	0.306	0.265	0.466	0.306	0.466	0.306
	4.4.2.2, 4.4.3.2	.14	.078	.14	.065	.23	.09	.23	.079
	9.3, 9.4	4.0	3.5	4.0	3.5	4.0	3.5	4.0	3.5
	5.3.2.3	.50	.25	.50	.25	.50	.25	.50	.25
	4.5.3, 5.3.2.4	.50	.30	.50	.30	.50	.30	.50	.30
) (°F)	7.3	100	70	100	70	100	70	100	70

d on strict interpretation of ASHRAE 90-75.

Low-Rise Apartment - Fan coil units with air-cooled reciprocating chiller; hot water boiler; two-pipe system with chilled/hot water; 100% recirculated air, and ventilation provided by infiltration. No economizer cycle, no humidification, no night setback.

Office Building - Constant volume, low pressure air system with terminal reheat; perimeter radiation and with economizer cycle; centrifugal chiller with constant condenser water temperature; cooling tower; hot water boiler. Winter humidification for 30% RH. No night setback.

Retail Store - Rooftop constant volume, low pressure air system, with economizer cycle; hot water boiler. DX and hot water heating coil (both in the unit), air cooled condenser, no perimeter radiation. No humidification, no night setback.

School - Unit ventilators with four pipe system using chilled water and hot water; centrifugal chiller; hot water boiler; cooling tower; and economizer cycle. No humidification, no night setback.

The same systems are used for the ASHRAE 90 buildings, except simulation is modified for controls to include reset by maximum demand and to allow for "deadband" requirements.

- *Hot Water Demand:* Residential domestic hot water demand was assumed to be 20 gallons per person per day. Other maximum loads were assumed to be:

	Maximum Peak Load (Gallons Per Hour)
Low-Rise Apartment Building	230
Office Building	160
Retail Store	40
School Building	720

- *Temperature Rise/Drop:* To establish flow rates, the same temperature rise/drop was used in both conventional and ASHRAE 90 modified buildings:

	°F.
Chilled Water	10
Hot Water	20
Condenser Water	10
Air, Retail Store	17
Air, All Others	20

- *Safety Factor:* As per conventional practice, a safety factor of 10 percent is used for conventional building load calculations and 0 percent for ASHRAE 90 buildings. The boilers were 20% oversized in both cases.

The actual application of ASHRAE 90 to the prototypical buildings was done by Kling-Lindquist, Inc., a prominent Philadelphia-based A/E design firm. Their responsibilities included the technical interpretation of the standard, the modification of the conventional buildings, the determination of annual energy requirements via computer simulation, and the estimation of building construction costs. The systems simulation models used in the analysis were developed and maintained by Ross F. Meriwether and Associates, San Antonio, Texas.

H. APPLICATION OF SOLAR ENERGY SYSTEMS TO THE PROTOTYPICAL BUILDINGS

Section 11 of the standard allows for an alternative approach in complying with the standard in which a nondepletable source of energy may be utilized and as such all "...energy supplied to the building shall be excluded from the total energy chargeable to the proposed design." In this instance, the standard prescriptive/performance approach of Sections 4 through 9 is used as a baseline for comparing the conventional energy replaced by the nondepleting source.

The energy augmentation approach of Section 11 was undertaken by sizing "optimum" solar energy systems utilizing existing flat-plate collector technology for each of the prototypical buildings in the study. "Optimum" systems in this instance were arrived at by selecting the system size which resulted in the lowest cost of solar energy provided to the structure.

Unlike the prescriptive/performance approach of Sections 4 through 9, a parameter by which we can express the technical and cost performance of a solar system is needed. A useful parameter for this purpose is the solar heat cost (SHC). SHC is defined as the ratio of annual ownership charges to annual solar heat collected. Specifically, SHC may be written:

$$\mathrm{SHC} = \frac{(C/A)\ (R)}{(\%\ S)\ (L/A)}$$

Where:

C/A = System cost per unit area of collector;

R = Amortization rate (assumed here to be 0.10);

% S = Fraction of the total building load supplied by solar heat, also called "percent solar";

L/A = Hot water, or total space heat plus hot water, load per unit area of collector.

Computer studies by ADL have resulted in extensive information on the performance of solar water heating and solar space heating systems, in various building types and various sections of the country. These studies have permitted the development of both technical correlations and a methodology for determining the percent solar as a function of the ratio of incident solar energy per unit load. The procedure for calculating SHC may be outlined as follows:

1) Select reasonable values of percent solar (% S) known from prior experience to be in the general vicinity of minimum solar heat costs.

2) Determine the ratio of incident solar energy per unit load (q_i/L) from previous correlations.

3) Compute the ratio of load per unit area (L/A) from the known annual incident radiation per unit area and the ratio of incident radiation per load established in the prior step.

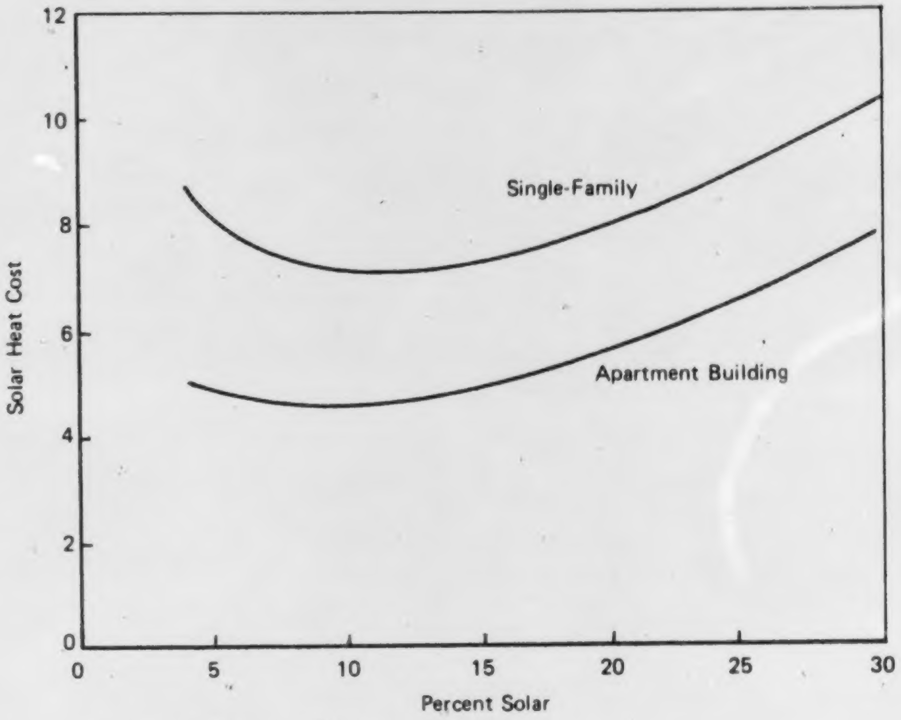
4) Compute solar collector area from the building load and the ratio of load per unit area determined above.

5) Establish cost per unit area as a function of solar collector area.

6) Compute solar heat cost, establish a data point, and repeat process with a different assumption of percent solar.

Given this, the "optimum" point at which the solar system was providing minimal SHC for each prototypical building was determined. Some of the more important trade-offs might be illustrated by a discussion of two example curves.

Figure II-1 shows the variation of solar heat cost with percent solar for both the single-family residence and multi-family apartment building in the Northeast (New York City, annual radiation: $.491 \times 10^6$ Btu/Yr./Sq. Ft.). This figure is unique for these particular structures, their demand loads, and geographic locations. The results show that the solar heat costs are generally lower for the apartment building, since the initial cost per unit area of collector of the larger solar system is less. The single-family house has a combined domestic hot water/space heating demand load of 157 million Btu per year, and at approximately 10% solar, the SHC is at a minimum. The low-rise apartment building has an annual combined demand load of nearly 2,700 million Btu, and at a 10% solar optimum also.



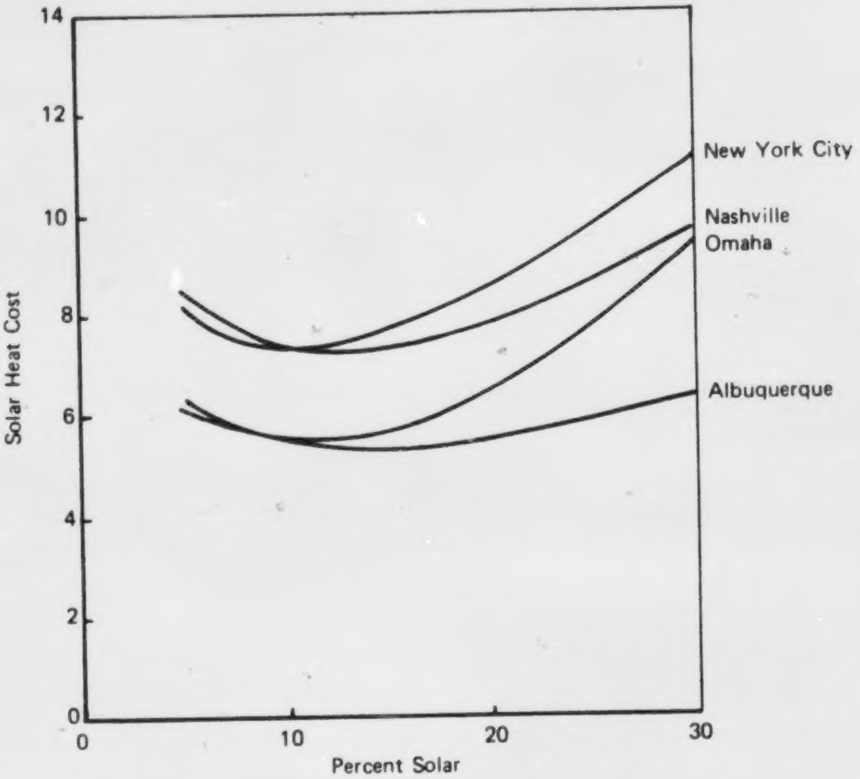
Source: Arthur D. Little, Inc.

FIGURE II–1 SOLAR HEAT COST VERSUS PERCENT-SOLAR, SPACE HEATING AND DOMESTIC WATER HEATING NEW YORK CITY (NORTHEAST)

Note that the percent solar can be increased, but at the expense of a higher SHC and a higher initial system cost, neither of which would be economically attractive to the client or to the design engineer. Figure II-1 also indicates that the minimum percent solar is not sharply defined, in that a factor of two change in percent solar (or collector area) away from the minimum solar heat cost shown, results in only about a 15% increase in solar heat cost.

Figure II-2 shows the solar heat cost for hot water and space heating for a single-family residence as a function of percent solar for the four geographical locations. The results show somewhat lower solar heat costs for the West and North Central regions due to higher solar insolation. For all locations, the minimum solar heat cost occurs in the range of 10% to 20% solar. Again, as discussed with reference to Figure II-1, the minimum system size is fairly broad with relatively little change in solar heat cost and indicates that the space heating load picked up by the solar system is only incremental to that of the building's domestic hot water load.

Once the most economical, or "optimum," solar system size is determined based upon SHC, its contribution to annual building energy requirements was then compared with those experienced under the prescriptive/performance approach of Sections 4 through 9.



Source: Arthur D. Little, Inc.

FIGURE II–2 SOLAR HEAT COST VERSUS PERCENT SOLAR, SPACE HEATING AND DOMESTIC WATER HEATING SINGLE-FAMILY RESIDENCE

CHAPTER III

IMPACT OF ASHRAE 90 ON ENERGY CONSUMPTION IN BUILDINGS

A. INTRODUCTION

Given the prototypical buildings, locations, and assumptions presented in the previous chapter, annual energy consumption was derived for the conventional buildings and compared to similar estimates derived under two separate approaches to ASHRAE 90:[1]

1) The "ASHRAE-90 modified" building resulting from the standard prescriptive/performance approach outlined in Sections 4 through 9 of the document, and

2) A modified building incorporating solar energy as a supplemental source of nondepleting energy as defined in Section 11 of the document.

In the latter case, it was necessary to evaluate how much of the building's conventional energy requirements could be supplemented by both a "minor application" of solar energy (domestic hot water) and a "major application" (domestic hot water and space heating). In each case, flat-plate collectors and conventional solar energy technology were assumed in order to derive the most economic solar energy system from a viewpoint of initial cost, not the system which would provide the highest percent solar.

The following sections will examine in detail the possible energy savings for each of the prototypical buildings, first under the prescriptive/performance approach, then under the energy augmentation approach. *Unless otherwise specified, all estimates on energy consumption are stated in terms of that energy supplied at the building boundary. Electrical energy usage does not include allowances for loss in efficiency due to its generation, transmission, or distribution.*

B. IMPACT OF THE PRESCRIPTIVE/PERFORMANCE APPROACH (Sections 4 through 9)

1. Single-Family Residence

The effect of ASHRAE 90 on energy utilization in the prototypical single-family residential units was to reduce overall consumption an average of 11.3%. As shown in Figure III-1, variations within the regions showed a noticeable split between the Northeast (14.7%) and North Central (15.1%) and the South (7.7%) and West (7.5%). This may

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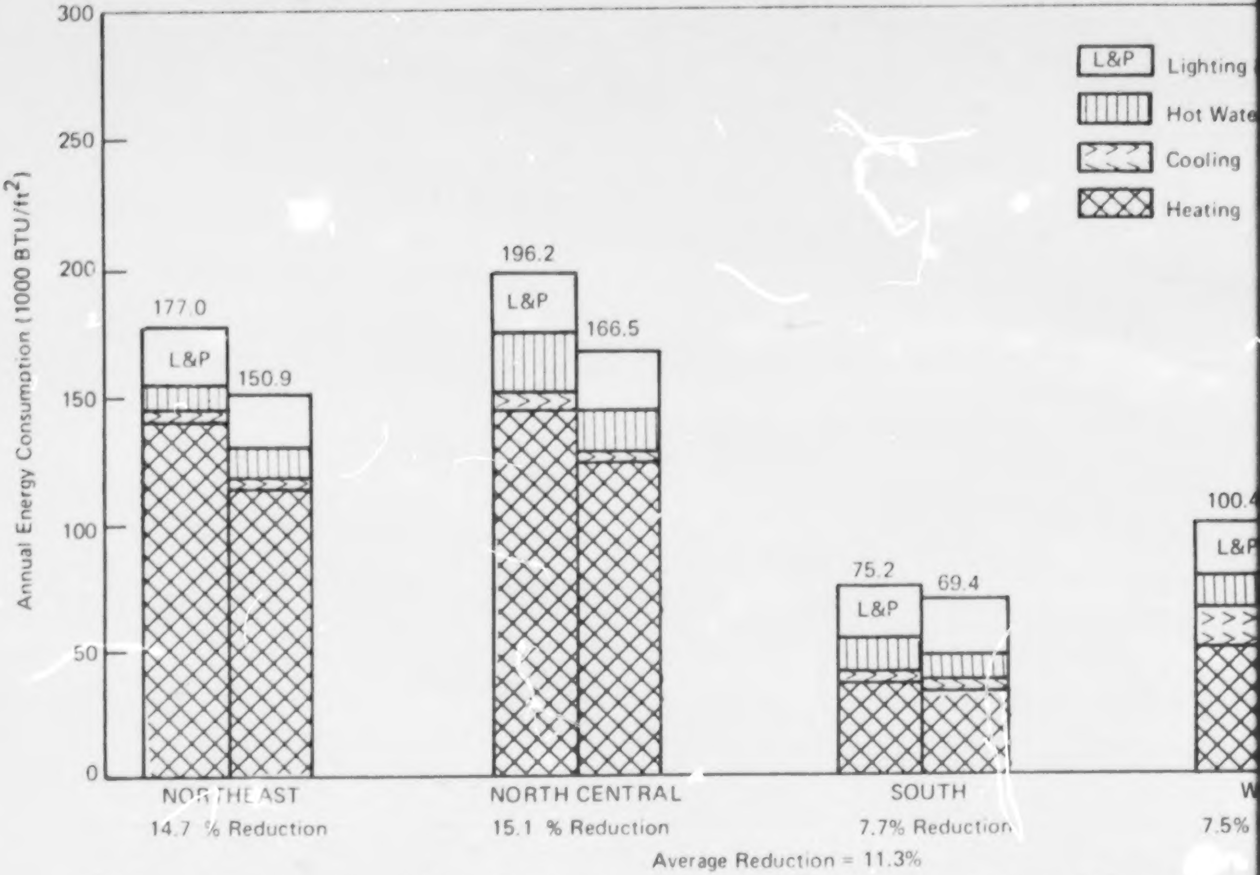
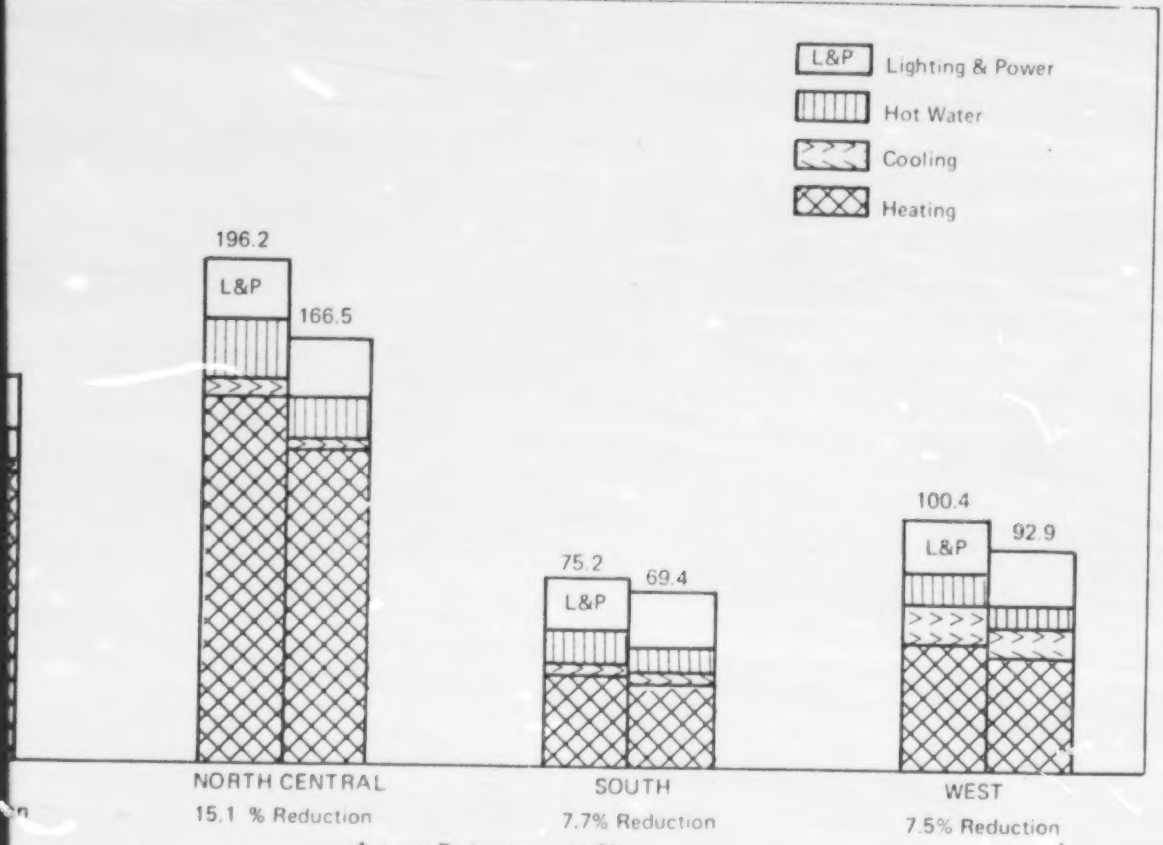
[1] The application of the systems analysis approach (Section 10) to the prototypical cases would require a more intensive effort than was possible under the time frame and funding of this study.



*Electrical energy usage measured at building boundary, and does not include allowances for loss in efficiency due to it transmission and distribution.

FIGURE III–1 COMPARATIVE ANNUAL ENERGY CONSUMPTION,* CONVENTIONAL VERSUS ASHRAE 90 MODIFIED PROTOTYPICAL SINGLE FAMILY RESIDENCES



Average Reduction = 11.3%

ge measured at building boundary, and does not include allowances for loss in efficiency due to its generation, tribution.

GURE III–1 COMPARATIVE ANNUAL ENERGY CONSUMPTION,* CONVENTIONAL VERSUS ASHRAE 90 MODIFIED PROTOTYPICAL SINGLE FAMILY RESIDENCES be accounted for, in part, by the fact that different prototypical buildings were used with the Northeast/North Central units being frame construction, and the South/West units being predominately masonry construction. Therefore, the key difference is in the heating requirements. In the two more northern locations, energy requirements for space heating are on the order of 75 to 78% of total energy consumption versus 47 to 57% for the South and West. Actual consumption (measured in 1,000 Btu per square foot of floor area) for the Northeast and North Central regions is approximately twice that of the more milder locations.

Another difference is accounted for by a higher assumed incoming water temperature in the South and West, thus lowering the energy requirements for domestic hot water. Lighting and power consumption were assumed equal across all locations.

A comparison of Tables III-1 and III-2 indicates that the majority of the reduction in actual energy consumption is attributable to the reduction in space heating requirements. For example, the North Central residence shows a 29,300 Btu per square foot total reduction in energy consumption, 20,400 Btu (70%) of which is reduced demand for space heating.

After space heating, most of the additional savings are accounted for by domestic hot water. While actual energy usage for comfort cooling under ASHRAE 90 shows reductions of approximately 30% in the South and West, the overall impact is considerably diluted when compared to space heating requirements, and as such, affects overall energy savings only slightly.

Reductions in lighting and power for single-family structures are negligible. Any appreciable savings here would not result from ASHRAE 90 but would have to be realized through consumer education.

2. Low-Rise Apartment Building

Unlike the single-family residence, the effect of ASHRAE 90 on the prototypical multi-family apartment building was to reduce average energy consumption by an average of 42.7%. As shown in Figure III-2, energy savings vary between 32.2% in the North Central region to 51.0% in the Northeast.

As in the single-family residence, ASHRAE 90 again appears to be very effective in reducing space heating requirements, which form the majority of actual unit energy savings (Tables III-3 and III-4). A case in point is the Northeast where out of a total unit savings of appoximately 129,400 Btu per square foot, 101,700 Btu per square foot (79%) was saved in heating.

However, unlike the single-family residence, significant savings in domestic water heating were also matched by savings in other end uses,

TABLE III-1

ANNUAL ENERGY CONSUMPTION* FOR CONVENTIONAL SINGLE-FAMILY RESIDENCE

Location	1000 Btu per Sq. Ft. (percent)			
	Heating	Hot Water	Cooling	Lighting & Powe
Northeast	137.2 (77.5)	15.7 (8.9)	3.6 (2.0)	20.5 (11.6)
North Central	147.0 (75.0)	22.5 (11.5)	5.8 (3.0)	20.5 (10.5)
West	52.7 (53.2)	11.8 (11.9)	15.4 (15.5)	20.5 (19.4)
South	35.4 (47.6)	12.0 (16.2)	7.3 (9.8)	20.5 (26.4)

*Electrical energy usage measured at building boundary, and does not include allowances loss in efficiency due to its generation, transmission, and distribution.

SOURCE: Kling-Lindquist, Inc., estimates.

TABLE III-1

NUAL ENERGY CONSUMPTION* FOR CONVENTIONAL SINGLE-FAMILY RESIDENCE

1000 Btu per Sq. Ft. (percent)				
Heating	Hot Water	Cooling	Lighting & Power	Total
137.2 (77.5)	15.7 (8.9)	3.6 (2.0)	20.5 (11.6)	177.0 (100.0)
147.0 (75.0)	22.5 (11.5)	5.8 (3.0)	20.5 (10.5)	195.8 (100.0)
52.7 (53.2)	11.8 (11.9)	15.4 (15.5)	20.5 (19.4)	100.4 (100.0)
35.4 (47.6)	12.0 (16.2)	7.3 (9.8)	20.5 (26.4)	75.2 (100.0)

ge measured at building boundary, and does not include allowances for e to its generation, transmission, and distribution.

st, Inc., estimates.

TABLE III-2

ANNUAL ENERGY CONSUMPTION* FOR ASHRAE 90 MODIFIED SINGLE-FAMILY RESID

Location	1000 Btu's per Sq. Ft. (percent)			
	Heating	Hot Water	Cooling	Lighting & Power
Northeast	117.2 (77.7)	11.0 (7.3)	2.2 (1.5)	20.5 (13.6)
North Central	126.6 (76.0)	15.8 (9.5)	3.6 (2.2)	20.5 (12.3)
West	52.7 (56.7)	8.3 (8.9)	11.4 (12.3)	20.5 (22.1)
South	35.3 (50.9)	8.4 (12.1)	5.2 (7.5)	20.5 (29.6)

*Electrical energy usage measured at building boundary, and does not include allowances loss in efficiency due to its generation, transmission, and distribution.

SOURCE: Kling-Lindquist, Inc., estimates.

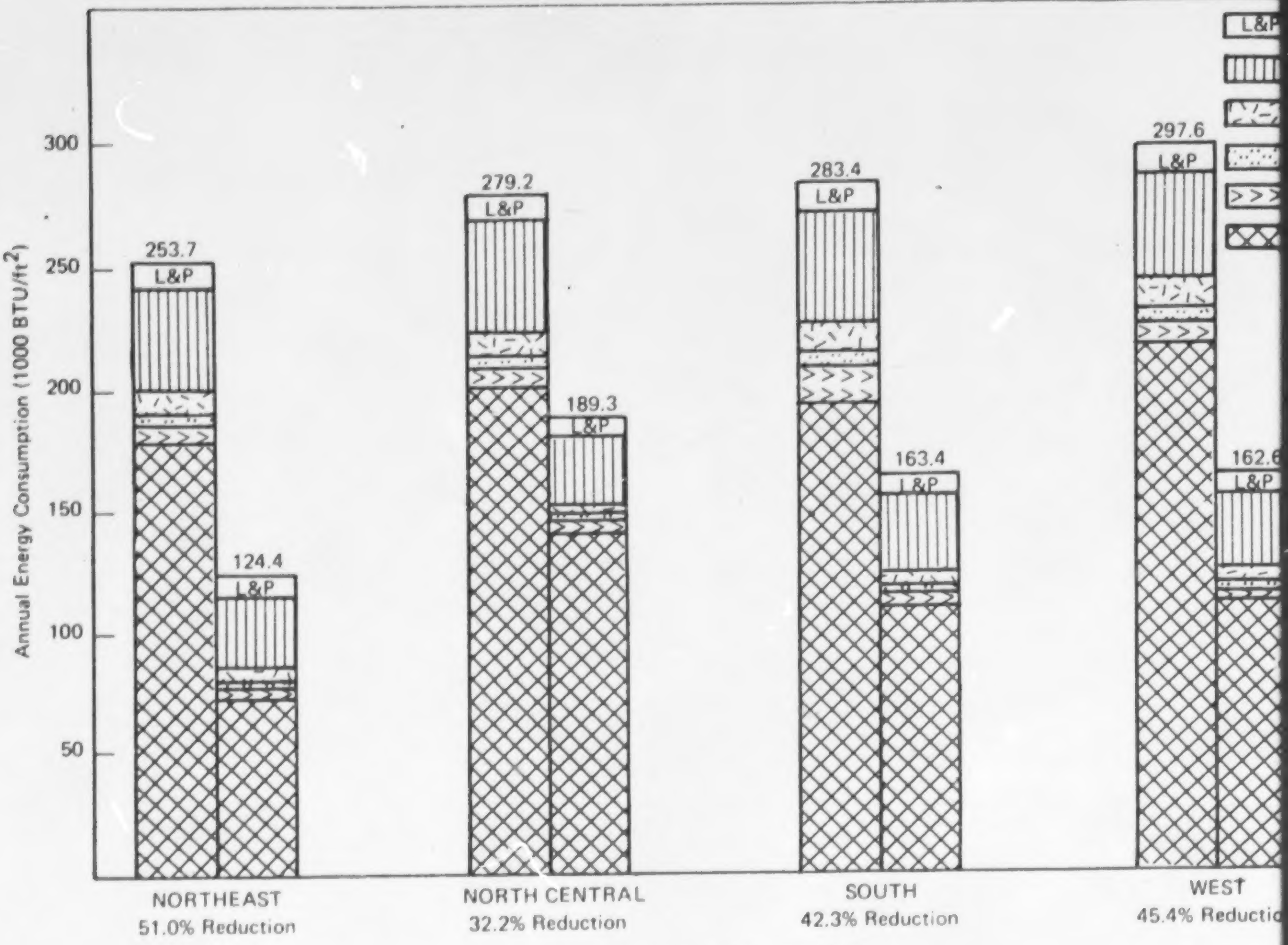
TABLE III-2

L ENERGY CONSUMPTION* FOR ASHRAE 90 MODIFIED SINGLE-FAMILY RESIDENCE

1000 Btu's per Sq. Ft. (percent)				
Heating	**Hot Water**	**Cooling**	**Lighting & Power**	**Total**
117.2 (77.7)	11.0 (7.3)	2.2 (1.5)	20.5 (13.6)	150.9 (100.0)
126.6 (76.0)	15.8 (9.5)	3.6 (2.2)	20.5 (12.3)	166.5 (100.0)
52.7 (56.7)	8.3 (8.9)	11.4 (12.3)	20.5 (22.1)	92.9 (100.0)
35.3 (50.9)	8.4 (12.1)	5.2 (7.5)	20.5 (29.6)	69.4 (100.0)

measured at building boundary, and does not include allowances for
o its generation, transmission, and distribution.

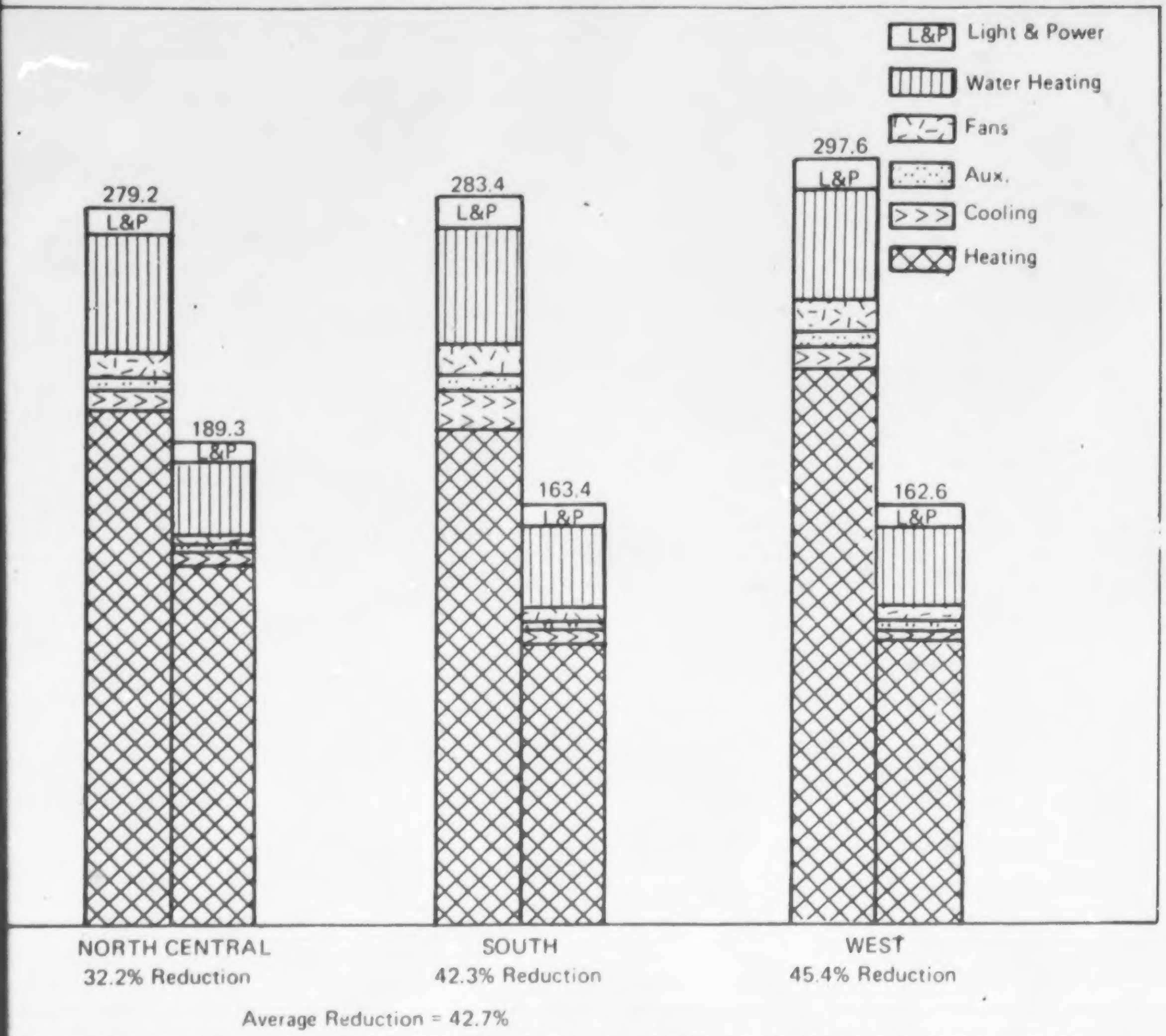
Inc., estimates.



Average Reduction = 42.7%

*Electrical energy usage measured at building boundary, and does not include allowances for loss in efficiency due to its generati and distribution.

FIGURE III–2 COMPARATIVE ANNUAL ENERGY CONSUMPTION,* CONVENTIONAL VERSUS ASHRAE 90 MODIFIED PROTYPICAL LOW-RISE MULTI-FAMILY APARTMENT BUILDINGS



ed at building boundary, and does not include allowances for loss in efficiency due to its generation, transmission

–2 COMPARATIVE ANNUAL ENERGY CONSUMPTION,* CONVENTIONAL VERSUS ASHRAE 90 MODIFIED PROTYPICAL LOW-RISE MULTI-FAMILY APARTMENT BUILDINGS

TABLE III-3

ANNUAL ENERGY CONSUMPTION[1] FOR CONVENTIONAL LOW-RISE APARTMENT BUILDING

Location	1000 Btu's per Sq. Ft. (percent)					
	Heating	Cooling (Chiller)	Auxiliaries[2]	Humidification	Fans	Water Heating
Northeast	177.0 (69.7)	7.8 (3.1)	3.3 (1.3)	0 (0)	9.6 (3.8)	43.9 (17.3)
North Central	200.0 (71.7)	9.7 (3.5)	3.7 (1.3)	0 (0)	9.6 (3.4)	43.9 (15.7)
West	213.8 (72.5)	8.0 (2.7)	5.3 (1.8)	0 (0)	12.5 (4.2)	43.9 (14.7)
South	194.6 (68.6)	15.3 (5.4)	5.0 (1.8)	0 (0)	12.5 (4.4)	43.9 (15.5)

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[1] Electrical energy usage measured at building boundary, and does not include allowances f efficiency due to its generation, transmission, and distribution.

[2] Includes hot water, chilled water, condenser pumps, cooling tower fans, and toilet exhau

SOURCE: Kling-Lindquist, Inc., based on computer simulation.

TABLE III-3

L ENERGY CONSUMPTION[1] FOR CONVENTIONAL LOW-RISE APARTMENT BUILDING

1000 Btu's per Sq. Ft. (percent)							
Heating	Cooling (Chiller)	Auxiliaries[2]	Humidification	Fans	Water Heating	Lighting & Power	Total
177.0 (69.7)	7.8 (3.1)	3.3 (1.3)	0 (0)	9.6 (3.8)	43.9 (17.3)	12.2 (4.8)	253.8 (100.0)
200.0 (71.7)	9.7 (3.5)	3.7 (1.3)	0 (0)	9.6 (3.4)	43.9 (15.7)	12.2 (4.4)	279.1 (100.0)
213.8 (72.5)	8.0 (2.7)	5.3 (1.8)	0 (0)	12.5 (4.2)	43.9 (14.7)	12.2 (4.1)	297.7 (100.0)
194.6 (68.6)	15.3 (5.4)	5.0 (1.8)	0 (0)	12.5 (4.4)	43.9 (15.5)	12.2 (4.3)	283.5 (100.0)

e measured at building boundary, and does not include allowances for loss in generation, transmission, and distribution.

illed water, condenser pumps, cooling tower fans, and toilet exhaust fans.

, Inc., based on computer simulation.

TABLE III-4

ANNUAL ENERGY CONSUMPTION[1] FOR ASHRAE 90 MODIFIED LOW-RISE APARTMENT BUILDI

	1000 Btu per Sq. Ft. (percent)						
Location	Heating	Cooling (Chiller)	Auxiliaries[2]	Humidification	Fans	Water Heating	Lig &
Northeast	75.3 (60.5)	3.9 (3.1)	2.1 (1.7)	0 (0)	2.7 (2.2)	30.7 (24.7)	
North Central	140.0 (74.0)	4.0 (2.1)	2.2 (1.2)	0 (0)	2.7 (1.4)	30.7 (16.2)	
West	111.0 (68.2)	5.0 (3.0)	2.3 (1.4)	0 (0)	4.0 (2.5)	30.7 (18.9)	
South	100.9 (67.8)	5.6 (3.4)	2.5 (1.5)	0 (0)	4.0 (2.5)	30.7 (18.8)	

---

[1] Electrical energy usage measured at building boundary, and does not include allowances for
efficiency due to its generation, transmission, and distribution.

[2] Includes hot water, chilled water, condenser pumps, cooling tower fans, and toilet exhaust

SOURCE: Kling-Lindquist, Inc., based on computer simluation.

TABLE III-4

RGY CONSUMPTION[1] FOR ASHRAE 90 MODIFIED LOW-RISE APARTMENT BUILDING

	1000 Btu per Sq. Ft. (percent)						
ting	Cooling (Chiller)	Auxiliaries[2]	Humidification	Fans	Water Heating	Lighting & Power	Total
5.3 0.5)	3.9 (3.1)	2.1 (1.7)	0 (0)	2.7 (2.2)	30.7 (24.7)	9.7 (7.8)	124.4 (100.0)
0.0 4.0)	4.0 (2.1)	2.2 (1.2)	0 (0)	2.7 (1.4)	30.7 (16.2)	9.7 (5.1)	189.3 (100.0)
1.0 8.2)	5.0 (3.0)	2.3 (1.4)	0 (0)	4.0 (2.5)	30.7 (18.9)	9.7 (6.0)	162.7 (100.0)
0.9 7.8)	5.6 (3.4)	2.5 (1.5)	0 (0)	4.0 (2.5)	30.7 (18.8)	9.7 (5.9)	163.4 (100.0)

asured at building boundary, and does not include allowances for loss in ration, transmission, and distribution.

d water, condenser pumps, cooling tower fans, and toilet exhaust fans.

nc., based on computer simluation.

specifically auxiliary HVA/C equipment (pumps, cooling tower fans), supply air fans, and lighting. Savings in space heating under ASHRAE 90 remain on the order of 75% of the total energy savings, with other end uses collectively accounting for only 25% of total energy reduction.

3. Office Building

Of all the building types investigated, the impact of ASHRAE 90 is greatest on the office building. This is true not only for an overall average percent reduction, but also within each region.

The application of ASHRAE 90 resulted in an average annual savings of 59.6% as shown in Figure III-3. The greatest saving was experienced in the Northeast region (61.5%), and the least in the South region (56.9%), although the relative reductions between regions is fairly consistent. A further examination of Figure III-3 shows that the reductions in the Northeast and North Central regions were similar as were those in the South and West regions. This again can be partially explained by the regional differences between the types of building analyzed: precast concrete walls with 30% fenestration versus sandwich panel curtain walls with 50% fenestration.

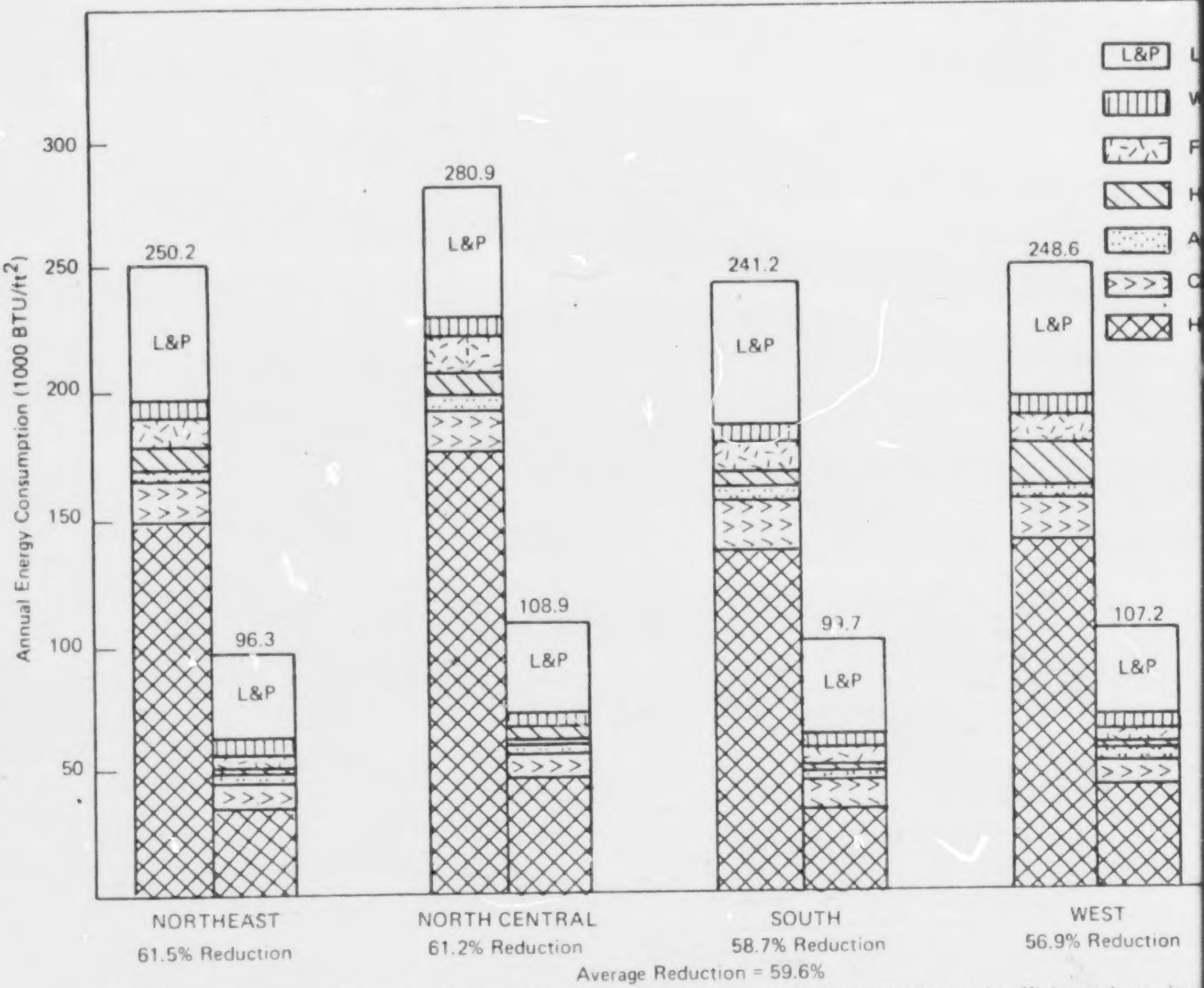
Comparing Tables III-5 and III-6, it is shown that reductions in space heating requirements are the major factor in overall energy savings. This is accounted for by the fact that the exterior walls in all four conventional buildings generally had poor overall thermal performance, and their modification under ASHRAE 90 resulted in a significant increase in U-value.

In the case of the office building, the collective energy demand for auxiliary HVA/C equipment, humidification, and supply fans exceeded the energy required to drive the chiller alone. As in other ASHRAE 90 modified buildings employing central HVA/C systems, significant energy savings were realized in these areas. Savings might have been even greater if economizer cycles (required by Section 5.6 of ASHRAE 90) had not been assumed for the conventional buildings also.

Of particular significance is the impact of ASHRAE 90 on the energy consumed in power humidification. The tables show a reduction of over 90% for all regions.

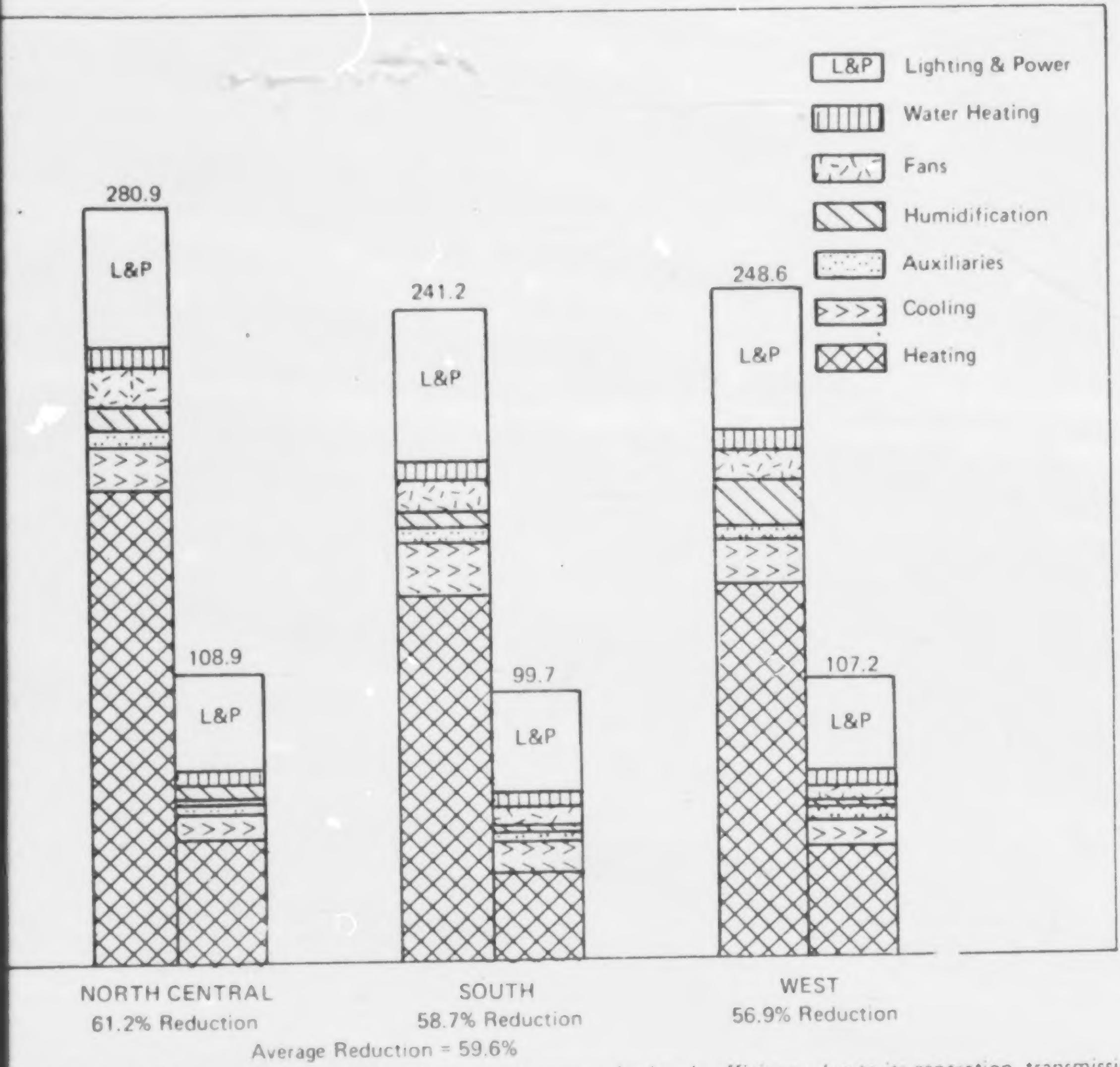
4. Retail Store

When applied to the prototypical retail store, ASHRAE 90 resulted in an average reduction of 40.1% in total energy consumption (Figure III-4 and Tables 7 and 8). Reductions were generally consistent beteen regions and were within the range of 38 to 43%. Unlike the other commercial buildings investigated, the actual energy requirements were significantly high even for the ASHRAE 90 modified structure, ranging between 162,000 to 171,000 Btu per square foot.



*Electrical energy usage measured at building boundary, and does not include allowances for loss in efficiency due to its g and distribution.

FIGURE III–3 COMPARATIVE ANNUAL ENERGY CONSUMPTION,* CONVENTIONAL VERSUS ASHRAE 90 MODIFIED PROTOTYPICAL OFFICE BUILDINGS



easured at building boundary, and does not include allowances for loss in efficiency due to its generation, transmission

3 COMPARATIVE ANNUAL ENERGY CONSUMPTION,* CONVENTIONAL VERSUS ASHRAE 90 MODIFIED PROTOTYPICAL OFFICE BUILDINGS

TABLE III-5

ANNUAL ENERGY CONSUMPTION[1] FOR CONVENTIONAL OFFICE BUILDING

Location	Heating	Cooling (Chiller)	Auxiliaries[2]	Humidification	Fans	Water Heating	Lig &
	1000 Btu's per Sq. Ft. (percent)						
Northeast	148.7 (59.4)	15.7 (6.3)	4.3 (1.7)	9.1 (3.6)	11.3 (4.5)	7.1 (2.8)	
North Central	175.4 (62.4)	16.2 (5.8)	6.3 (2.2)	8.8 (3.1)	13.1 (4.7)	7.1 (2.5)	
West	140.0 (56.3)	16.3 (6.6)	3.0 (1.2)	16.2 (6.5)	11.6 (4.7)	7.1 (2.8)	
South	136.8 (56.7)	20.5 (8.5)	5.0 (2.1)	5.9 (2.4)	11.8 (4.9)	7.1 (2.9)	

---

[1] Electrical energy usage measured at building boundary, and does not include allowances for efficiency due to its generation, transmission, and distribution.

[2] Includes hot water, chilled water, condenser pumps, cooling tower fans, and toilet exhaust

SOURCE: Kling-Lindquist, Inc., based on computer simulation.

TABLE III-5

Y CONSUMPTION[1] FOR CONVENTIONAL OFFICE BUILDING

1000 Btu's per Sq. Ft. (percent)

ng	Cooling (Chiller)	Auxiliaries[2]	Humidification	Fans	Water Heating	Lighting & Power	Total
7 4)	15.7 (6.3)	4.3 (1.7)	9.1 (3.6)	11.3 (4.5)	7.1 (2.8)	54.0 (21.6)	250.2 (100.0)
4 4)	16.2 (5.8)	6.3 (2.2)	8.8 (3.1)	13.1 (4.7)	7.1 (2.5)	54.0 (19.2)	280.9 (100.0)
0 3)	16.3 (6.6)	3.0 (1.2)	16.2 (6.5)	11.6 (4.7)	7.1 (2.8)	54.0 (21.7)	248.6 (100.0)
8 7)	20.5 (8.5)	5.0 (2.1)	5.9 (2.4)	11.8 (4.9)	7.1 (2.9)	54.0 (22.4)	241.1 (100.0)

ured at building boundary, and does not include allowances for loss in tion, transmission, and distribution.

water, condenser pumps, cooling tower fans, and toilet exhaust fans.

c., based on computer simulation.

TABLE III-6

ANNUAL ENERGY CONSUMPTION[1] FOR ASHRAE 90 MODIFIED OFFICE BUILDING

	1000 Btu per Sq. Ft. (percent)					
Location	Heating	Cooling (Chiller)	Auxiliaries[2]	Humidification	Fans	Water Heating
Northeast	35.6 (36.9)	9.7 (10.0)	2.7 (2.8)	0.6 (0.6)	4.5 (4.7)	5.0 (5.2)
North Central	46.5 (42.7)	10.5 (9.6)	2.9 (2.7)	0.7 (0.6)	5.1 (4.7)	5.0 (4.6)
West	42.0 (39.2)	10.9 (10.1)	3.4 (3.2)	1.3 (1.2)	6.4 (6.0)	5.0 (4.7)
South	33.8 (33.9)	12.5 (12.5)	3.6 (3.6)	0.3 (0.3)	6.2 (6.2)	5.0 (5.0)

---

[1] Electrical energy usage measured at building boundary, and does not include allowances f efficiency due to its generation, transmission, and distribution.

[2] Includes hot water, chilled water, condenser pumps, cooling tower fans, and toilet exhau

SOURCE: Kling-Lindquist, Inc., based on computer simulation.

TABLE III-6

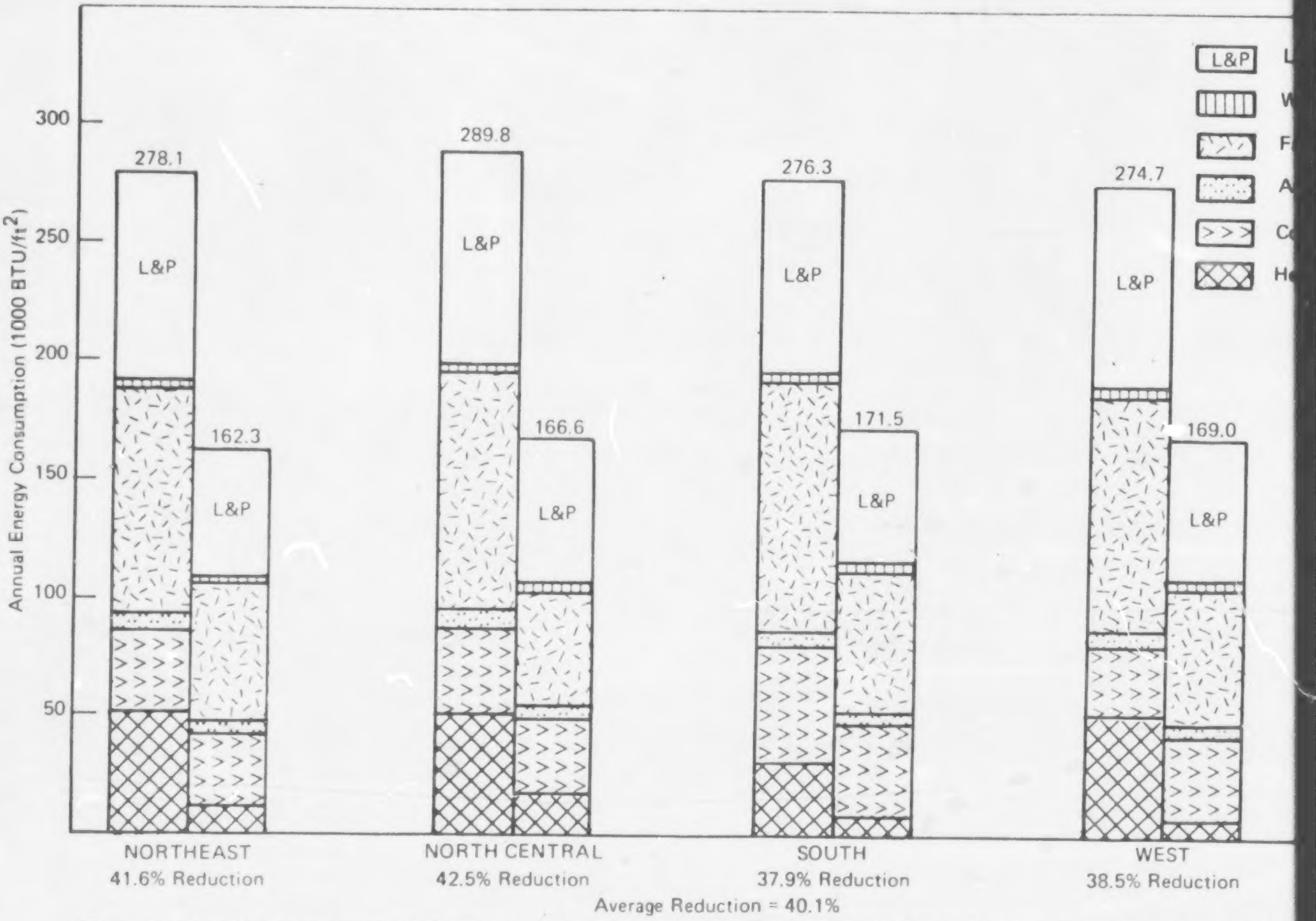
GY CONSUMPTION[1] FOR ASHRAE 90 MODIFIED OFFICE BUILDING

1000 Btu per Sq. Ft. (percent)							
ing	Cooling (Chiller)	Auxiliaries[2]	Humidification	Fans	Water Heating	Lighting & Power	Total
.6 .9)	9.7 (10.0)	2.7 (2.8)	0.6 (0.6)	4.5 (4.7)	5.0 (5.2)	38.3 (39.7)	96.4 (100.0)
.5 .7)	10.5 (9.6)	2.9 (2.7)	0.7 (0.6)	5.1 (4.7)	5.0 (4.6)	38.3 (35.1)	109.0 (100.0)
.0 .2)	10.9 (10.1)	3.4 (3.2)	1.3 (1.2)	6.4 (6.0)	5.0 (4.7)	38.3 (35.7)	107.3 (100.0)
3.8 3.9)	12.5 (12.5)	3.6 (3.6)	0.3 (0.3)	6.2 (6.2)	5.0 (5.0)	38.3 (38.4)	99.7 (100.0)

asured at building boundary, and does not include allowances for loss in ration, transmission, and distribution

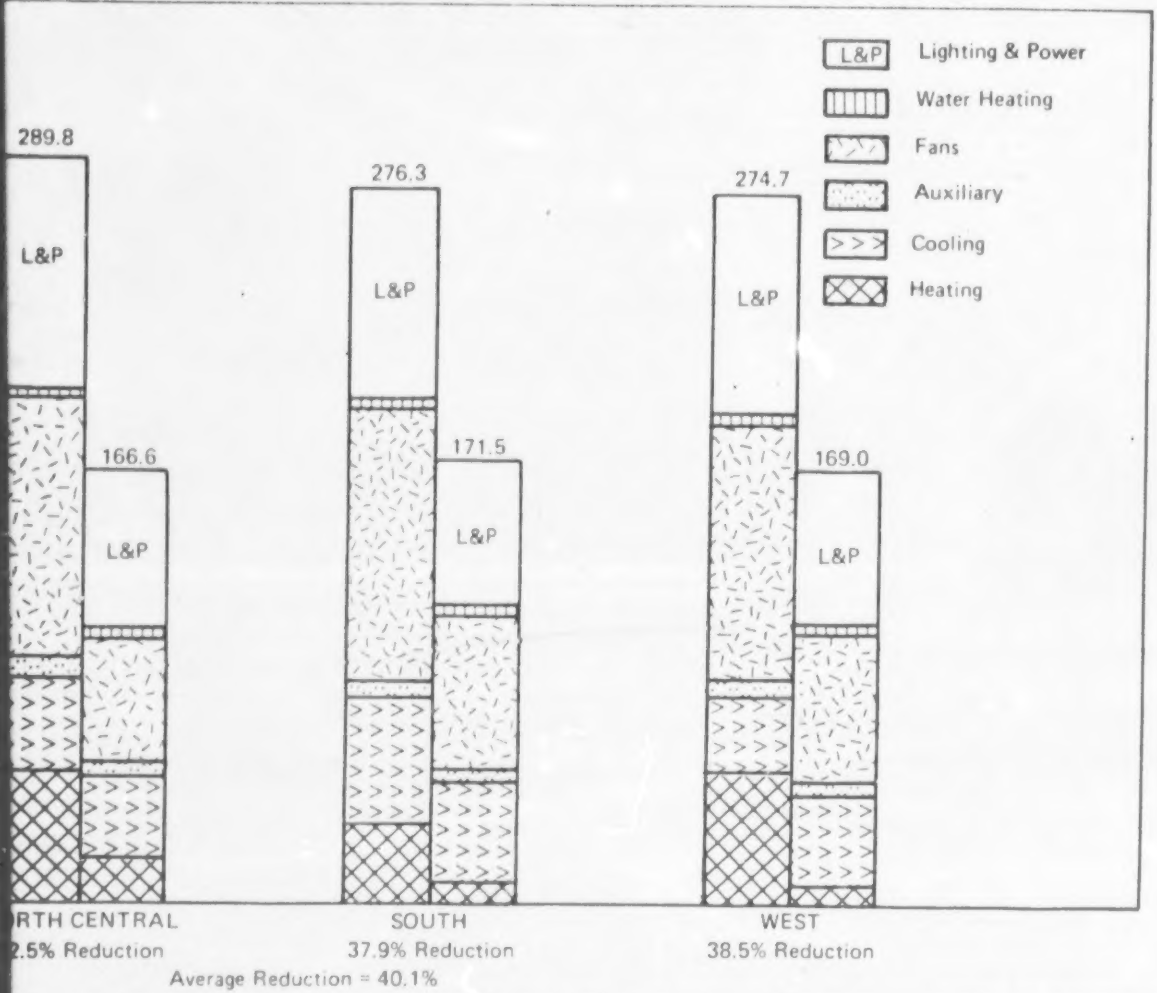
d water, condenser pumps, cooling tower fans, and toilet exhaust fans.

nc., based on computer simulation.



* Electrical energy usage measured at building boundary, and does not include allowances for loss in efficiency due to its generation, trans

FIGURE III–4 COMPARATIVE ANNUAL ENERGY CONSUMPTION,* CONVENTIONAL VERSUS ASHRAE 90 MODIFIED PROTOTYPICAL RETAIL STORES



ling boundary, and does not include allowances for loss in efficiency due to its generation, transmission and distribution.

OMPARATIVE ANNUAL ENERGY CONSUMPTION,* CONVENTIONAL
ERSUS ASHRAE 90 MODIFIED PROTOTYPICAL RETAIL STORES

TABLE III-7

ANNUAL ENERGY CONSUMPTION[1] FOR CONVENTIONAL RETAIL STORE

	1000 Btu per Sq. Ft. (percent)						
Location	Heating	Cooling (Chiller)	Auxiliaries[2]	Humidification	Fans	Water Heating	Lig &
Northeast	50.9 (18.3)	33.7 (12.1)	5.7 (2.0)	0 (0)	96.0 (34.5)	2.6 (1.0)	
North Central	50.1 (17.3)	36.9 (12.8)	6.7 (2.3)	0 (0)	104.0 (35.9)	2.6 (0.9)	
West	52.7 (19.2)	28.5 (10.4)	5.7 (2.1)	0 (0)	96.0 (34.9)	2.6 (0.9)	
South	30.6 (11.1)	46.5 (16.8)	6.7 (2.4)	0 (0)	100.6 (36.4)	2.6 (1.0)	

---

[1] Electrical energy usage measured at building boundary, and does not include allowances for efficiency due to its generation, transmission, and distribution.

[2] Includes hot water, chilled water, condenser pumps, cooling tower fans, and toilet exhaust

SOURCE: Kling-Lindquist, Inc., based on computer simulation.

TABLE III-7

GY CONSUMPTION[1] FOR CONVENTIONAL RETAIL STORE

	1000 Btu per Sq. Ft. (percent)						
ing	Cooling (Chiller)	Auxiliaries[2]	Humidification	Fans	Water Heating	Lighting & Power	Total
.9 .3)	33.7 (12.1)	5.7 (2.0)	0 (0)	96.0 (34.5)	2.6 (1.0)	89.2 (32.1)	278.1 (100.0)
0.1 7.3)	36.9 (12.8)	6.7 (2.3)	0 (0)	104.0 (35.9)	2.6 (0.9)	89.2 (30.8)	289.5 (100.0)
2.7 9.2)	28.5 (10.4)	5.7 (2.1)	0 (0)	96.0 (34.9)	2.6 (0.9)	89.2 (32.5)	274.7 (100.0)
0.6 1.1)	46.5 (16.8)	6.7 (2.4)	0 (0)	100.6 (36.4)	2.6 (1.0)	89.2 (32.3)	276.2 (100.0)

asured at building boundary, and does not include allowances for loss in ration, transmission, and distribution.

d water, condenser pumps, cooling tower fans, and toilet exhaust fans.

Inc., based on computer simulation.

TABLE III-8

ANNUAL ENERGY CONSUMPTION[1] FOR ASHRAE 90 MODIFIED RETAIL STORE

	1000 Btu's per Sq. Ft. (percent)						
Location	Heating	Cooling (Chiller)	Auxiliaries[2]	Humidification	Fans	Water Heating	Li &
Northeast	10.1 (6.2)	30.4 (18.7)	3.8 (2.3)	0 (0)	55.1 (33.9)	1.8 (1.1)	
North Central	18.1 (10.9)	30.5 (18.3)	3.9 (2.3)	0 (0)	51.1 (30.7)	1.8 (1.1)	
West	11.5 (6.8)	34.1 (20.2)	4.1 (2.4)	0 (0)	56.3 (33.3)	1.8 (1.0)	
South	7.5 (4.4)	38.6 (22.5)	4.3 (2.5)	0 (0)	58.2 (33.9)	1.8 (1.0)	

---

[1] Electrical energy usage measured at building boundary, and does not include allowances for efficiency due to its generation, transmission, and distribution.

[2] Includes hot water, chilled water, condenser pumps, cooling tower fans, and toilet exhaust

SOURCE: Kling-Lindquist, Inc., based on computer simulation.

TABLE III-8

ERGY CONSUMPTION[1] FOR ASHRAE 90 MODIFIED RETAIL STORE

1000 Btu's per Sq. Ft. (percent)							
ating	Cooling (Chiller)	Auxiliaries[2]	Humidification	Fans	Water Heating	Lighting & Power	Total
0.1 (6.2)	30.4 (18.7)	3.8 (2.3)	0 (0)	55.1 (33.9)	1.8 (1.1)	61.1 (37.6)	162.3 (100.0)
8.1 0.9)	30.5 (18.3)	3.9 (2.3)	0 (0)	51.1 (30.7)	1.8 (1.1)	61.1 (36.7)	166.5 (100.0)
1.5 (6.8)	34.1 (20.2)	4.1 (2.4)	0 (0)	56.3 (33.3)	1.8 (1.0)	61.1 (36.2)	168.9 (100.0)
7.5 4.4)	38.6 (22.5)	4.3 (2.5)	0 (0)	58.2 (33.9)	1.8 (1.0)	61.1 (35.6)	171.5 (100.0)

asured at building boundary, and does not include allowances for loss in ration, transmission, and distribution.

d water, condenser pumps, cooling tower fans, and toilet exhaust fans.

nc., based on computer simulation.

A major explanation of both the high initial consumption (275,000 to 290,000 Btu per square foot) and the relatively low percentage reduction lies in the type of building. Retail stores similar to the prototypical building have high internal loads, predominantly lighting, which both offset space heating requirements and increase cooling requirements. The energy requirements of the supply fans are considerable, due to the use of rooftop units and high volumes of delivered air for cooling.

As in the other nonresidential buildings, energy requirements for heating were reduced significantly (between 60 and 80% on average). However, space heating accounted for only 11 to 20% of total energy requirements of the conventional structures. Thus, the normally strong impact of ASHRAE 90 on space heating requirements was somewhat lost by the retail stores' high energy requirements for supply fan horsepower. This is a direct effect of high cooling loads accounted for by the large lighting loads generally found in mercantile-type establishments.

While ASHRAE 90 did reduce lighting requirements under the modified buildings, they remained the most significant end use, averaging between 35 and 38% of total unit energy consumption.

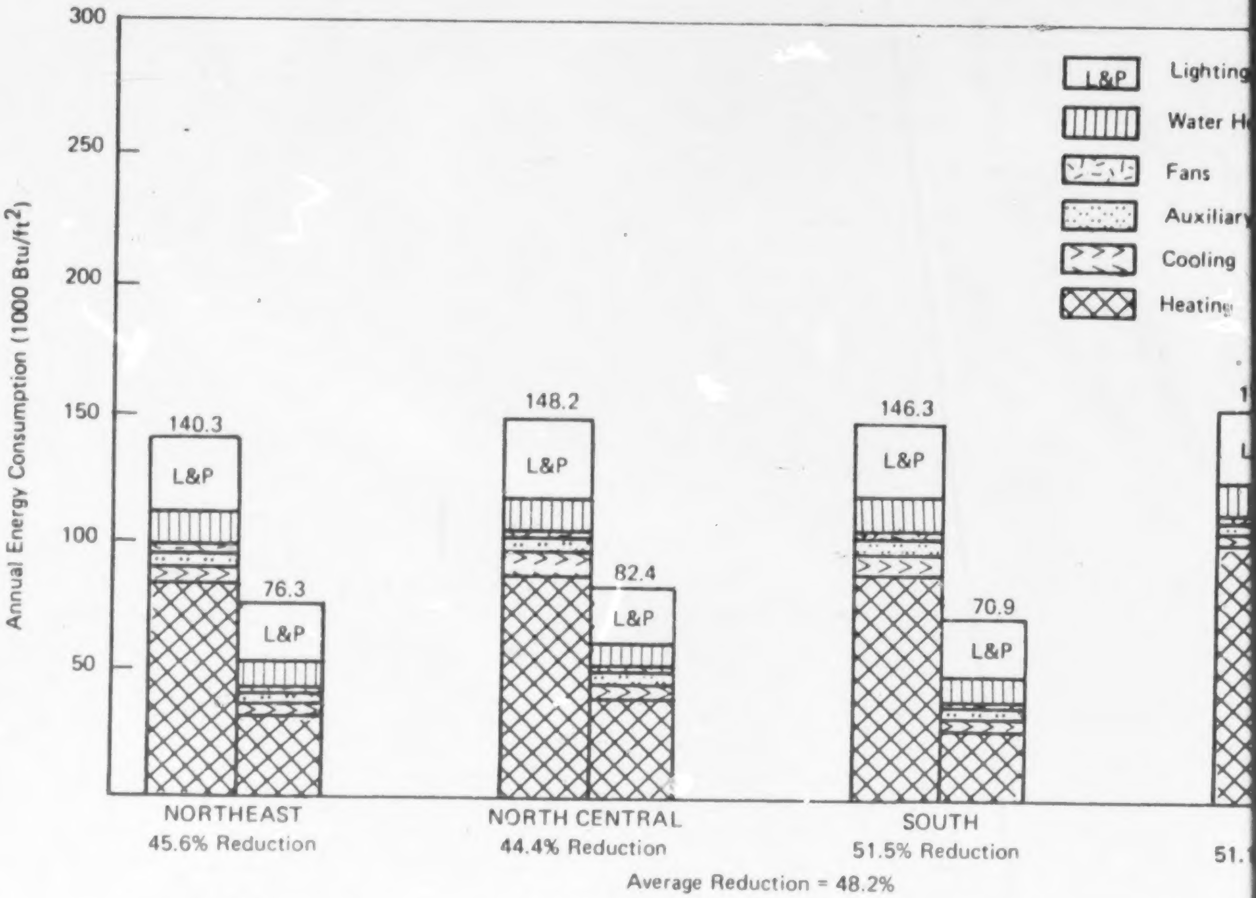
5. School Building

The average annual reduction in overall energy requirements of the four prototypical school buildings due to the application of ASHRAE 90 was found to be 48.2% (Figure III-5). The reductions of the Northeast and North Central regions' buildings were in the range of 45 to 46% and were generally lower than those of the South and West regions. Again, this may be due largely to a variation in the type of construction, although the ASHRAE 90 appears to be equally effective in reducing annual energy consumption for both types of buildings.

As shown in Table III-9 and III-10, space heating is the predominant energy requirement, accounting for between 57 to 62% of annual requirements in the conventional structures. As in other nonresidential buildings, ASHRAE 90 reduces space heating requirements 50 to 60%, an amount which accounts for over two-thirds of the reduction in overall total energy consumption. Moderate reduction in chiller requirements, water heating, and lighting account for the remainder.

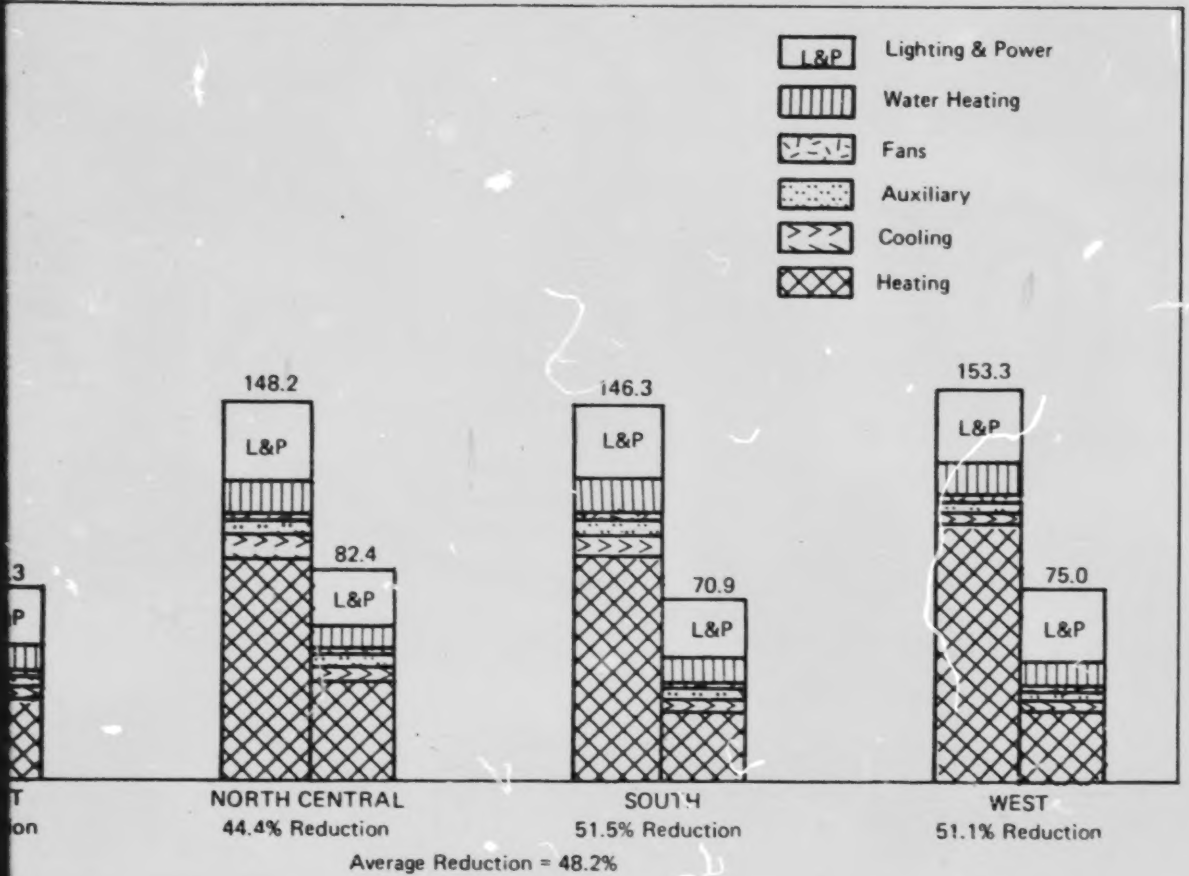
C. COMPARATIVE IMPACTS

From the preceding findings, it can be concluded that ASHRAE 90 has a significant impact in reducing annual energy consumption for most of the prototypical building types investigated. Table III-11 summarizes the percent reduction in annual energy consumption by building type and geographical location. It appears that ASHRAE 90 has a more significant effect in the colder climates, although the type of building construction selected for the South and West regions was often lighter and less



*Electrical energy usage measured at building boundary, and does not include allowances for loss in efficiency due to transmission and distribution.

FIGURE III–5 COMPARATIVE ANNUAL ENERGY CONSUMPTION,* SCHOOL BUILDINGS CONVENTIONAL VERSUS ASHRAE 90 MODIFIED PROTOTYPICAL SCHOOL BUILDINGS



usage measured at building boundary, and does not include allowances for loss in efficiency due to its generation, distribution.

GURE III–5 COMPARATIVE ANNUAL ENERGY CONSUMPTION,* SCHOOL BUILDINGS CONVENTIONAL VERSUS ASHRAE 90 MODIFIED PROTOTYPICAL SCHOOL BUILDINGS

TABLE III-9

ANNUAL ENERGY CONSUMPTION[1] FOR CONVENTIONAL SCHOOL BUILDING

	1000 Btu per Sq. Ft. (percent)						
Location	Heating	Cooling (Chiller)	Auxiliaries[2]	Humidification	Fans	Water Heating	Lig &
Northeast	80.6 (57.5)	6.7 (4.8)	3.8 (2.7)	0 (0)	1.5 (1.1)	13.5 (9.5)	
North Central	85.4 (58.1)	7.8 (5.3)	4.6 (3.1)	0 (0)	1.5 (1.0)	13.5 (9.2)	
West	94.9 (61.9)	5.9 (3.8)	2.9 (1.9)	0 (0)	2.0 (1.3)	13.5 (8.8)	
South	83.7 (57.3)	8.6 (5.9)	4.4 (3.0)	0 (0)	1.9 (1.3)	13.5 (9.2)	

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[1] Electrical energy usage measured at building boundary, and does not include allowances fo
efficiency due to its generation, transmission, and distribution.

[2] Includes hot water, chilled water, condenser pumps, cooling tower fans, and toilet exhaus

SOURCE: Kling-Lindquist, Inc., based on computer simulation.

TABLE III-9

CONSUMPTION[1] FOR CONVENTIONAL SCHOOL BUILDING

1000 Btu per Sq. Ft. (percent)						
Cooling (Chiller)	Auxiliaries[2]	Humidification	Fans	Water Heating	Lighting & Power	Total
6.7 (4.8)	3.8 (2.7)	0 (0)	1.5 (1.1)	13.5 (9.6)	34.1 (24.3)	140.2 (100.0)
7.8 (5.3)	4.6 (3.1)	0 (0)	1.5 (1.0)	13.5 (9.2)	34.1 (23.2)	146.9 (100.0)
5.9 (3.8)	2.9 (1.9)	0 (0)	2.0 (1.3)	13.5 (8.8)	34.1 (22.2)	153.3 (100.0)
8.6 (5.9)	4.4 (3.0)	0 (0)	1.9 (1.3)	13.5 (9.2)	34.1 (23.3)	146.2 (100.0)

red at building boundary, and does not include allowances for loss in
ion, transmission, and distribution.

ater, condenser pumps, cooling tower fans, and toilet exhaust fans.

, based on computer simulation.

TABLE III-10

ANNUAL ENERGY CONSUMPTION[1] FOR ASHRAE 90 MODIFIED SCHOOL BUILDING

	1000 Btu's per Sq. Ft. (percent)						
Location	**Heating**	**Cooling (Chiller)**	**Auxiliaries[2]**	**Humidification**	**Fans**	**Water Heating**	**L &**
Northeast	33.2 (43.5)	3.7 (4.8)	1.7 (2.2)	0 (0)	1.0 (1.3)	9.5 (12.4)	
North Central	38.9 (47.1)	3.9 (4.7)	1.9 (2.3)	0 (0)	1.0 (1.2)	9.5 (11.5)	
East	31.6 (42.0)	3.7 (4.9)	2.0 (2.7)	0 (0)	1.1 (1.5)	9.5 (12.6)	
South	26.0 (36.6)	5.0 (7.0)	2.1 (2.9)	0 (0)	1.1 (1.5)	9.5 (13.4)	

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[1] Electrical energy usage measured at building boundary, and does not include allowances fo efficiency due to its generation, transmission, and distribution.

[2] Includes hot water, chilled water, condenser pumps, cooling tower fans, and toilet exhaus

SOURCE: Kling-Lindquist, Inc., based on computer simulation.

TABLE III-10

ENERGY CONSUMPTION[1] FOR ASHRAE 90 MODIFIED SCHOOL BUILDING

1000 Btu's per Sq. Ft. (percent)							
Heating	Cooling (Chiller)	Auxiliaries[2]	Humidification	Fans	Water Heating	Lighting & Power	Total
33.2	3.7	1.7	0	1.0	9.5	27.3	76.4
(43.5)	(4.8)	(2.2)	(0)	(1.3)	(12.4)	(35.7)	(100.0)
38.9	3.9	1.9	0	1.0	9.5	27.3	82.5
(47.1)	(4.7)	(2.3)	(0)	(1.2)	(11.5)	(33.1)	(100.0)
31.6	3.7	2.0	0	1.1	9.5	27.3	75.2
(42.0)	(4.9)	(2.7)	(0)	(1.5)	(12.6)	(36.3)	(100.0)
26.0	5.0	2.1	0	1.1	9.5	27.3	71.0
(36.6)	(7.0)	(2.9)	(0)	(1.5)	(13.4)	(38.5)	(100.0)

measured at building boundary, and does not include allowances for loss in eneration, transmission, and distribution.

lled water, condenser pumps, cooling tower fans, and toilet exhaust fans.

, Inc., based on computer simulation.

insulated than that of the Northeast and North Central regions. The large percent of annual energy consumption which is accounted for by space heating is particularly susceptible to the effectiveness of ASHRAE 90. In general, reductions in space heating typically accounted for between 60 to 75% of the reductions in total energy consumption.

A more obvious fact shown in Table III-11 also shows that the estimated reductions possible in single-family residences are considerably less than those estimated in the other prototypical buildings investigated. This might be attributed to one of two reasons:

1) The document is less effective in increasing overall residential U-values, or

2) the conventional residences selected were more thermally efficient than their nonresidential counterparts.

Both reasons are acceptable. Within recent years, statistics on insulation markets show that there has been a major growth in the amount of insulation per housing start, and that the residential units of the 1970's are far more efficient than the houses built as recently as 10 years ago.

On the other hand, the interpretation of ASHRAE 90 resulted in few modifications to the single-family units. The standard was met by only a minor reduction in glass area, and without having to adopt double glazing. In this respect, a straight prescriptive standard such as HUD's recently adopted Minimum Property Standard 51b would have been more demanding than ASHRAE 90 for the single-family units investigated.

Table III-11 also shows the single, most important energy demand is for space heating, with the exception of the retail store which has major lighting requirements, and subsequently, major requirements for HVA/C auxiliary equipment and supply fans. As a result, the retail store shows the least percentage reduction in total energy consumption of all the nonresidential buildings, and thus, the highest unit energy demand after application of ASHRAE 90.

If one did not agree with the selection of the conventional prototypical buildings and initial design assumptions, then perhaps the level of energy usage for the ASHRAE 90 modified buildings is a better measure of the effectiveness of the document. The lowest unit demands of the prototypical buildings which had been modified under ASHRAE 90 were on the order of 67,000 to 72,000 Btu per square foot. By taking a weighted average of the annual energy consumption across all buildings types investigated, it can be estimated that a strict interpretation of the document would probably account for a reduction in overall energy consumption for new (1976) construction to about 128,000 Btu per square foot. Within this, new residential construction after modification by ASHRAE 90 would be on the order of 135,000 Btu per square foot, and new nonresidential construction around 115,000 Btu per square foot.

TABLE III - 11

REDUCTION IN ANNUAL ENERGY CONSUMPTION, BY BUILDING TYPE AND GEOGRAPHICAL LOCATION

	Northeast	North Central	South	West
Single-family Residence	14.7	15.1	7.7	7.5
Low-rise Apartment Building	51.0	32.2	42.3	45.4
Office Building	61.5	61.2	58.7	56.9
Retail Store	41.6	42.5	37.9	38.5
School Building	45.6	44.4	51.5	51.1

	Average Reduction in Annual Energy Consumption (percent)	Major End Use of Energy (ranked in order)
Single-family Residences		Heating Domestic Hot Water Lighting and Power
Low-rise Apartment Building	42.7	Heating Domestic Hot Water
Office Building	59.6	Heating Lighting and Power
Retail Store	40.1	Supply Fans Lighting and Power Heating
School Building	48.1	Heating Lighting and Power Domestic Hot Water

SOURCE: Computer Simulation of Prototypical Buildings

ADL noted that neither the above weighted average consumption nor the consumption for any of the prototypical nonresidential structures after the application of ASHRAE 90 approaches the 55,000 Btu per square foot "goal" (at the property line) previously proposed by the General Services Administration (GSA) for all new government buildings. From this, it could be concluded that although ASHRAE 90 is effective in reducing overall energy consumption mainly through reducing space heating requirements. The standard thus is a reasonable first step in reducing energy consumption in newly constructed buildings.

D. KEY SECTIONS IN THE PRESCRIPTIVE/PERFORMANCE APPROACH

As in all written standards, certain sections are more critical than others in accomplishing the objective. ASHRAE 90 is no exception. Based upon the interpretation of the standard for a variety of building types, it is possible to determine which specific sections appear to be more "effective" in curtailing overall building energy consumption.

Unfortunately, the intricacies to reducing building energy consumption, particularly nonreisdential buildings, result in certain trade-offs. For example, a reduction in lighting level would result in lower cooling loads, and might possibly increase space heating requirements. Decreased ventilation rates could lead to higher infiltration. Thus, any comparative analysis of the effects of certain sections of ASHRAE 90 is subjective, at best, and should not be assumed conclusive without further investigation.

Table III-12 lists eight selected parameters which contribute to the reduction of energy consumption under the prescriptive/performance approach of ASHRAE 90. For each parameter, a quantitative approximation reflecting the extent to which it contributes to annual energy reduction is given. The total reduction shown for each building type is the percent reduction for that building type averaged across the four regions.

Again, further analysis would be required to determine a more accurate impact of the individual parameters. However, the following conclusions might be drawn from Table III-12:

- The most effective parameters (and thus specific sections of ASHRAE 90) vary by building type. However, there appears to be a distinct difference between the critical parameters for single-family residences, and those for nonresidential buildings.

- With few exceptions, all of the parameters listed have some influence in each building type. In nonresidential construction, it appears as if those sections dealing with HVA/C systems and winter design conditions are the two most effective

TABLE III-12

PARAMETERS ATTRIBUTABLE TO ENERGY REDUCTION[1,2]
(Percent)

Parameter (Applicable Sections from ASHRAE 90)	Single-Family Residence	Low-Rise Apartment	Office Building	Retai Stor
• Summer Design Conditions (4.2.5 & 5.3.2)	1.8	4.6	3.4	3.4
• Winter Design Conditions (4.2.5 & 5.3.2)	3.9	8.8	12.4	7.3
• Overall Thermal Requirements $-U_o$ (4.3)	0.9	8.0	8.0	4.0
• Lighting (9.3.1)	0	1.8	6.3	8.6
• Ventilation (5.3.2.3)	0	2.3	7.0	5.5
• Infiltration (4.5.3 & 5.3.2.4)	1.3	0.8	1.5	1.0
• Domestic Hot Water (7.3)	2.5	5.0	1.0	0.5
• HVA/C Equipment, Systems, and Control (6.3, 6.4 & 6.6)	0.9	11.4	20.0	9.5
Total Reduction	11.3	42.7	59.6	40.1

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[1] Figures shown are an average of the prototypical buildings analyzed.

[2] Attributed reduction is based upon educated judgment. Further analysis is required to determi impact on contributing parameters.

SOURCE: Kling-Lindquist, Inc. Estimates

TABLE III-12

PARAMETERS ATTRIBUTABLE TO ENERGY REDUCTION[1,2]
(Percent)

	Single-Family Residence	Low-Rise Apartment	Office Building	Retail Store	School
	1.8	4.6	3.4	3.4	2.5
	3.9	8.8	12.4	7.3	7.6
	0.9	8.0	8.0	4.0	4.0
	0	1.8	6.3	8.6	4.4
	0	2.3	7.0	5.5	13.0
	1.3	0.8	1.5	1.0	2.5
	2.5	5.0	1.0	0.5	3.0
trol	0.9	11.4	20.0	9.5	11.1
	11.3	42.7	59.6	40.1	48.1

e prototypical buildings analyzed.
educated judgment. Further analysis is required to determine a more accurate
.

ntes

in the low-rise apartment and office building, while those sections dealing with HVA/C equipment lighting are important in the retail store. The school building, with its high ventilation requirements, appears to be affected most by the section dealing with ventilation.

- Those sections of ASHRAE 90 which appear to be comparatively ineffective in reducing overall energy consumption relate to summer design conditions and domestic hot water. In the latter case, this is not to say that the section within the document dealing with domestic hot water is weak, but only that its contribution to the overall energy requirements of the building are relatively small in all but residential construction.

E. SELECTED IMPACTS ON BUILDING MATERIALS AND HVA/C EQUIPMENT

The application of ASHRAE 90 to the prototypical buildings resulted in a redeisgn of each structure. This led to a comparison of the physical characteristics between the conventional and ASHRAE 90 modified buildings which, in turn, form the basis for the economic impact discussed in Chapter VI. A few of the more important impacts of the standard on buildings materials and characteristics are as follows:

- *Exterior Glass* - ASHRAE 90 led to a reduction in glass area (percent fenestration) in 12 of the 20 prototypical cases investigated. Reductions ranged up to 30% of the glass area assumed in the conventional buildings as shown in Table III-13. In only one case--the office building--was insulating glass required across four regions to meet the standard.

- *Exterior Wall Area* - The reduction in glass was matched by an increase in exterior opaque wall materials. As shown in Table III-14, increases ranged up to 30% of the existing wall area. However, virtually all increases were less than 8%.

- *Insulation* - ASHRAE 90 called for more insulation, both batt-type for residential construction and rigid-type for nonresidential construction. Additional requirements ranged from approximately 80 up to 300 pounds of fiberglass per residential unit.

- *Lamps/Lighting Fixtures* - Reduction in lamp requirements (watts per square foot) and lighting fixtures (number per

TABLE III-13

REDUCTION IN GLASS AREA ATTRIBUTABLE TO APPLICATION OF ASHRAE 90 TO THE PROTOTYPICAL BUILDINGS

(Percent Fenestration)

	Northeast	North Central	South	West
Single-Family Residence	0	-4.1	0	-1.3
Low-Rise Apartment Building	-11.0	-21.3	0	-6.0
Office Building	-16.7	-3.3	-30.6	-28.2
Retail Store	0	-13.3	0	0
School	-7.5	-20.0	0	0

SOURCE: Arthur D. Little, Inc.; Kling-Lindquist, Inc.

TABLE III-14

INCREASE IN OPAQUE WALL AREA ATTRIBUTABLE TO APPLICATION OF ASHRAE 90 TO THE PROTOTYPICAL BUILDINGS

(Percent Wall Area)

	Northeast	North Central	South	West
Single-Family Residence	0	0.7	0	0.3
Low-Rise Apartment Building	3.4	6.5	0	1.8
Office Building	7.1	1.4	30.6	28.2
Retail Store	0	2.4	0	0
School	1.9	5.0	0	0

SOURCE: Arthur D. Little, Inc.; Kling-Lindquist, Inc.

square foot) and lighting fixtures (number per square foot) varied by building type and was confined to nonresidential construction:

	Lamps (percent)	Lighting Fixtures (percent)
Office Building	-28	-25
Retail Store	-30	-25
School Building	-15	-15

Additional switching was required for more individual area control of lights.

- *HVA/C System Capacities* - Table III-15 summarizes the reduction in heating and cooling capacities (also see Appendix A). These reductions in equipment size are significant, and represent a "credit" to the initial cost of the ASHRAE 90 modified buildings. In general, reductions in heating systems exceeded those in cooling systems, while those in nonresidential construction exceeded those in the single-family residence. The unweighted average reduction in heating system capacity was 42%, compared to 31% for the cooling system.

- *HVA/C Auxiliaries* - Table III-16 shows the percent reduction in required kilowatt (or horsepower) requirements for four types of HVA/C equipment: chiller, pumps, cooling tower fans, and supply fans. Again, the unweighted average reduction of 44% across all equipment types and geographical locations is significant. Reductions were lowest for the school and greatest for the office building. Reductions also were generally less for the West region.

F. IMPACT OF THE ENERGY AUGMENTATION APPROACH

For each prototypical building, a solar energy package was designed incorporating a specific collector area which provided the minimum solar heat cost for that particular building type, location, and load--either water heating or total space heating plus water heating. Table III-17 is a tabulation of percent solar and corresponding collector area for domestic water heating systems for the five building types and four geographic locations. Table III-18 presents comparable information for total space heating and domestic water heating.

The solar percentages shown correspond with the minimum solar heat cost. These tables illustrate that the percent solar for "optimum" cost is appreciably higher for the solar hot water only (30-50%) than for the space heating (10-20%), since the annnual hot water load profile is

TABLE III-15

REDUCTION IN HEATING AND COOLING SYSTEM CAPACITIES, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED BUILDINGS

(Percent)

Region	Single-Family	Low-Rise Apartments	Office Building	Retail Store	School
NORTHEAST					
Heating	27	47	36	50	55
Cooling	20	32	42	34	44
NORTH CENTRAL					
Heating	26	36	36	43	51
Cooling	21	39	42	36	45
SOUTH					
Heating	20	59	29	49	60
Cooling	16	28	16	15	24
WEST					
Heating	20	57	28	49	62
Cooling	15	35	38	22	48
AVERAGE REDUCTION					
Heating	23	50	32	48	57
Cooling	18	33	35	27	40

SOURCE: Kling-Lindquist, Inc., based on strict interpretation of ASHRAE 90-75.

TABLE III-16

REDUCTION IN HVA/C EQUIPMENT KW RATING CONVENTIONAL VS. ASHRAE 90 MODIFIED BUILDINGS

(Percent)

	Northeast	North Central	South	West	Average
Low Rise Apartment					
Chiller	29	42	43	30	36
Pumps[1]	27	30	26	25	27
Cooling Towers[2]	27	47	62	73	52
Supply Fans	72	72	68	68	70
Average	39	48	50	49	46
Office Building					
Chiller	50	43	42	16	38
Pumps	58	69	47	20	49
Cooling Towers	57	61	45	—	54
Supply Fans	61	61	47	45	54
Average	57	59	45	27	49
Retail Store					
Chiller	30	37	51	14	33
Pumps	31	38	35	19	31
Cooling Towers	51	53	46	63	53
Supply Fans	43	51	42	41	44
Average	39	45	44	34	40
School					
Chiller	40	44	44	17	36
Pumps	50	47	41	15	38
Cooling Towers	44	48	35	--	42
Supply Fans	33	35	46	45	40
Average	42	44	42	26	39
OVERALL AVERAGE	44	49	45	35	44

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[1] Includes hot water, chilled water, and condenser water pumps.

[2] Fan air cooler

Source: Kling-Lindquist, Inc.; Arthur D. Little, Inc. Estimates

TABLE III-17

"OPTIMUM" SOLAR SYSTEM FOR DOMESTIC WATER HEATING

	Northeast		North Central		South		
	% Solar	Collector Area	% Solar	Collector Area	% Solar	Collector Area	% S
Single Family Residence	35	40	30	20	40	35	
Low-Rise Apartment Building	30	1,100	30	640	40	1,290	
Office Building	30	410	30	240	40	480	
Retail Store	30	120	30	70	40	140	
School Building	30	770	30	450	40	900	

SOURCE: Arthur D. Little, Inc.

TABLE III-17

MUM" SOLAR SYSTEM FOR DOMESTIC WATER HEATING

Northeast		North Central		South		West	
Solar	Collector Area	% Solar	Collector Area	% Solar	Collector Area	% Solar	Collector Area
35	40	30	20	40	35	50	30
30	1,100	30	640	40	1,290	40	820
30	410	30	240	40	480	40	300
30	120	30	70	40	140	40	90
30	770	30	450	40	900	40	580

Inc.

TABLE III-18

"OPTIMUM" SOLAR SYSTEM FOR DOMESTIC WATER HEATING AND SPACE HEATING

	Northeast		North Central		South		
	% Solar	Collector Area	% Solar	Collector Area	% Solar	Collector Area	% Sol
Single Family Residence	10	60	10	50	10	30	2
Low-Rise Apartment Building	10	1,070	10	940	10	1,070	1
Office Building	10	1,570	10	1,480	10	1,360	1
Retail Store	10	440	10	340	10	260	1
School Building	10	1,000	10	830	10	1,140	1

SOURCE: Arthur D. Little, Inc.

TABLE III-18

PTIMUM' SOLAR SYSTEM FOR DOMESTIC WATER HEATING AND SPACE HEATING

	heast	North Central		South		West	
Sol	Collector Area	% Solar	Collector Area	% Solar	Collector Area	% Solar	Collector Area
2	60	10	50	10	30	20	70
1	1,070	10	940	10	1,070	10	880
1	1,570	10	1,480	10	1,360	10	1,060
1	440	10	340	10	260	10	320
1	1,000	10	830	10	1,140	10	800

much more uniform than the total space heating/water heating load profile, and therefore presents a better demand. By increasing the collector areas for the combined system, the percent solar would also be increased; however, the resultant solar heat costs would not be "optimal."

Table III-19 compares the percent reduction in annual building energy load for total space heating and domestic water heating for each of the five building types.

Interestingly enough, in only two cases did the "optimum" solar systems actually reduce the energy loads of the conventional buildings below those of the buildings modified under Sections 4 through 9. These were both in the residential sector.

It therefore appears that the use of solar energy as a nondepletable energy source is not as effective in reducing annual building energy demand as in the prescriptive/performance approach when the solar system is designed to meet a minimum economic criteria. Had the solar system been designed to maximize percent solar, this would probably not have been true.

No investigation was made of the combined application of both a solar energy approach and the standard prescriptive/performance approach of ASHRAE 90. There is no reason, technological or otherwise, which would prohibit such an approach. The resulting reduction in annual building energy demand would be considerable.

TABLE III-19

COMPARATIVE REDUCTION IN UNIT ANNUAL ENERGY CONSUMPTION, SPACE HEATING PLUS DOMESTIC WA

(percent)

	Northeast		North Central		South	
	P/P[1]	EA[2]	P/P	EA	P/P	EA
Single Family Residence	17	10	11	10	5	10
Low-Rise Apartments	49	10	30	10	44	10
Office Building	72	10	71	10	67	10
Retail Store	76	10	61	10	73	10
School Building	52	10	50	10	60	10

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[1] Standard prescriptive/performance approach; Sections 4 through 9.

[2] Energy augmentation approach utilizing solar energy; Section 11.

SOURCE: Arthur D. Little, Inc.

TABLE III-19

UNIT ANNUAL ENERGY CONSUMPTION, SPACE HEATING PLUS DOMESTIC WATER HEATING ONLY

(percent)

Northeast		North Central		South		West	
P/P[1]	EA[2]	P/P	EA	P/P	EA	P/P	EA
17	10	11	10	5	10	8	20
49	10	30	10	44	10	43	10
72	10	71	10	67	10	72	10
76	10	61	10	73	10	67	10
52	10	50	10	60	10	61	10

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erformance approach; Sections 4 through 9.

roach utilizing solar energy; Section 11.

e, Inc.

CHAPTER IV

IMPACT OF ASHRAE 90 ON BUILDING ECONOMICS

A. INTRODUCTION

The modification of the conventional buildings to meet the criteria set forth in ASHRAE 90 cannot be accomplished without some impact on both the initial (capital) and annual operating costs of the building. Changes in these costs and the resultant implications for building owners are discussed in this chapter. Impact on building economics will be reviewed separately for both the prescriptive/performance approach, and the solar energy augmentation approach to ASHRAE-90.

B. OPERATING COST IMPACT OF THE PRESCRIPTIVE/PERFORMANCE APPROACH

For each of the prototypical building types and locations, the annual operating costs were estimated for both the conventional and ASHRAE-90 modified buildings. In order to regionalize the analysis, energy costs as of June 1975 were compiled based upon published and unpublished data from the Federal Power Commission, the Federal Energy Administration, the American Gas Association, The Bureau of Mines, and phone calls to selected fuel oil dealers.

Costs for the three primary conventional fuels are shown in Table IV-1. Average unit costs for each region were determined by a weighted average technique based upon the average fuel cost for each Standard Economic Area (SEA) within that region, and the 1970 population of the SEA as reported by the Bureau of the Census. The rates are divided into both residential and commercial values and indicate approximately a 25% differential between the two, with residential energy being more costly.

In order to account for step functions in the rate structures, the unit costs shown are based upon the amount of fuel required to meet a minimum benchmark level for space heating in each SEA. Therefore, the estimates shown should represent the weighted unit value of energy saved in going from a conventional to an ASHRAE-90 modified building, which by definition is less than the unit cost of the same energy at the first step of the rate schedule.

As expected, fuel oil costs are roughly equal between regions and for both residential and commercial cases, while gas and electricity rates are highest in the Northeast and lowest in the South and West.

Given the unit costs in Table IV-1, annual energy costs were derived for each prototypical building based upon the annual amount of energy (by fuel type) consumed by each building. (See Appendix B.) Comparing similar results for the conventional versus ASHRAE-90 modified building, an estimate

TABLE IV-1

WEIGHTED-AVERAGE ENERGY PRICES, BY REGION, JUNE 1975

	RESIDENTIAL			COMMERC	
	Gas ($/Mcf)	Oil (¢/Gal.)	Electricity (¢/Kwh)	Gas ($/Mcf)	Oil (¢/Gal.)
Northeast	1.72	38.5	4.55	1.37	38.5
North Central	1.10	36.0	2.58	0.86	36.0
South	1.04	38.0	2.38	0.74	38.0
West	1.08	39.0	2.23	0.78	39.0

SOURCES: FPC; FEA; AGA; BuMines; Arthur D. Little, Inc., estimates.

TABLE IV-1

EIGHTED-AVERAGE ENERGY PRICES, BY REGION, JUNE 1975

RESIDENTIAL			COMMERCIAL		
s cf)	Oil (¢/Gal.)	Electricity (¢/Kwh)	Gas ($/Mcf)	Oil (¢/Gal.)	Electricity (¢/Kwh)
2	38.5	4.55	1.37	38.5	4.30
0	36.0	2.58	0.86	36.0	2.44
	38.0	2.38	0.74	38.0	2.36
	39.0	2.23	0.78	39.0	2.05

Mines; Arthur D. Little, Inc., estimates.

of energy cost savings was determined. Table IV-2 summarizes the annual unit savings in dollars per square foot, and the percent reduction these savings represent over energy costs for the conventional building.

Actual savings are greatest in the Northeast, and in one case (retail store) exceeded $1.00 per square foot. However, most cost savings were on the order of $0.20 to $0.70 per square foot. Savings in the single-family residences were somewhat lower and less broader ($0.05 to $0.14 per square foot) than the cost reductions realized for commercial construction ($0.12 to $1.05 per square foot).

The general magnitude of these savings is significant, even when based on present energy costs, and should in themselves generate some interest among various types of building owners. For example, a 1972 survey of owning and operating costs for office buildings[1] showed that 35% of the average annual operating costs were accounted for by utility bills. The same report also showed that energy costs are responsible for over 13% of building revenues, second only to property taxes.

C. INITIAL COST IMPACT OF THE PRESCRIPTIVE/PERFORMANCE APPROACH

Perhaps the most interesting facet of the study was the determination of the change in initial building cost incurred by the application of Sections 4 through 9 of ASHRAE-90.

As indicated previously, the redesign of each of the prototypical buildings produced sufficient data on changes in materials and equipment to allow a detailed costing effort to be undertaken. Table IV-3 lists eleven building component systems and subsystems which were identified as being impacted by ASHRAE-90. The table shows component cost by building type and region expressed as cost per unit floor area. Construction costs were estimated using recognized industry practices, and represent the cost to the owner including contractor's overhead and profit. The estimates have also been regionally adjusted for each of the four regions according to the indices shown in Appendix C.

The estimated change in initial cost for each prototypical building is shown in Table IV-4 and was determined given the cost factors of Table IV-3. As an example, consider the office building in Omaha:

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[1] "1972 Office Building Experience Exchange Report," Building Owners and Managers Association International, 1973

TABLE IV-2

ANNUAL SAVINGS IN ENERGY COST

(Dollars Per Sq. Ft. and Percent Reduction in Annual Cost)

	Northeast	North Central	South
Single-Family Residence	0.136 (15%)	0.048 (13%)	0.049 (10%)
Low-Rise Apartment	0.626 (43%)	0.178 (39%)	0.228 (48%)
Office Building	0.718 (47%)	0.349 (44%)	0.291 (39%)
Retail Store	1.048 (35%)	0.673 (39%)	0.576 (34%)
School	0.299 (36%)	0.143 (34%)	0.138 (34%)

SOURCE: Arthur D. Little, Inc., estimates.

TABLE IV-2

ANNUAL SAVINGS IN ENERGY COST

rs Per Sq. Ft. and Percent Reduction in Annual Cost)

Northeast	North Central	South	West
0.136 (15%)	0.048 (13%)	0.049 (10%)	0.061 (9%)
0.626 (43%)	0.178 (39%)	0.228 (48%)	0.189 (45%)
0.718 (47%)	0.349 (44%)	0.291 (39%)	0.242 (38%)
1.048 (35%)	0.673 (39%)	0.576 (34%)	0.414 (30%)
0.299 (36%)	0.143 (34%)	0.138 (34%)	0.116 (33%)

Inc., estimates.

ESTIMATED UNIT COSTS OF CONVENTIONAL VS. ASHRAE 90-75 MODIFIED BUILDINGS

(Dollars per Sq. Ft. of Floor Area)

	Single-Family		Multi-Family		Office Building		Retail Store		School	
	Conventional	ASHRAE 90-75	Conventional	ASHRAE 90-75	Conventional	ASHRAE 90-75	Conventional	ASHRAE 90-75	Conventional	ASHRAE 90-75
EXTERIOR WALLS										
NE	1.70	1.70	0.92	0.96	2.69	3.14	0.85	0.99	1.62	1.65
NC	1.65	1.66	0.90	0.96	2.62	2.95	0.83	1.04	1.58	1.66
S	2.54	2.54	1.30	1.36	2.33	2.41	0.75	0.86	1.39	1.41
W	1.99	1.99	1.58	1.67	2.60	2.70	0.83	0.96	1.55	1.57
GLASS										
NE	1.23	1.23	1.15	1.02	1.03	1.07	0.40	0.40	0.56	0.52
NC	1.20	1.15	1.12	0.88	1.00	1.24	0.39	0.34	0.55	0.44
S	1.05	1.05	1.01	1.01	1.50	1.30	0.35	0.35	0.49	0.49
W	1.19	1.17	1.13	1.05	1.68	1.50	0.39	0.39	0.55	0.55
ROOF										
NE	1.11	1.18	0.56	0.60	0.73	0.88	2.18	2.62	2.18	2.62
NC	1.08	1.15	0.55	0.58	0.71	0.86	2.12	2.77	2.12	2.77
S	.04	1.04	0.50	0.53	0.64	0.77	1.91	2.20	1.91	2.40
W	1.16	1.16	0.55	0.58	0.71	0.86	2.14	2.46	2.14	2.79
FLOOR INSULATION (Where Applicable)										
NE		0.03		0.02		----		0.02		----
NC		0.03		0.02		----		0.02		----
S		0.08		0.02		----		0.02		----
W		0.12		0.02		----		0.02		----
HVA/C EQUIPMENT										
NE	0.83	0.78	1.88	1.65	3.88	3.50	2.65	2.34	2.87	2.47
NC	0.84	0.79	1.89	1.67	3.91	3.52	2.67	2.36	2.89	2.50
S	0.85	0.80	1.93	1.70	3.99	3.60	2.72	2.41	2.95	2.54
W	0.84	0.79	1.91	1.68	3.94	3.56	2.69	2.38	2.92	2.51
HVA/C DISTRIBUTION										
NE	1.01	0.94	2.31	2.04	4.73	4.26	3.24	2.86	3.50	3.02
NC	1.05	0.97	2.40	2.12	4.90	4.42	3.[illegible]	2.97	3.63	3.13
S	0.92	0.86	2.11	1.87	4.32	3.90	2.96	2.62	3.20	2.76
W	1.05	0.98	2.40	2.12	4.91	4.43	3.37	2.97	3.64	3.14
HVA/C CONTROLS										
NE	0.36	0.36	0.06	0.06	0.39	0.50	0.11	0.11	1.13	1.13
NC	0.36	0.36	0.06	0.06	0.40	0.52	0.11	0.11	1.14	1.14
S	0.33	0.33	0.05	0.05	0.35	0.45	0.10	0.10	1.04	1.04
W	0.36	0.36	0.06	0.06	0.40	0.51	0.11	0.11	1.12	1.12
LIGHTING										
NE	0.42	0.42	0.35	0.35	2.20	2.17	0.9[illegible]	0.95	1.53	1.46
NC	0.43	0.43	0.36	0.36	2.27	2.23	1.01	0.98	1.58	1.50
S	0.42	0.42	0.35	0.35	2.20	2.17	0.98	0.95	1.53	1.46
W	0.42	0.42	0.35	0.35	2.22	2.19	0.99	0.96	1.55	1.48
ELECTRICAL DISTRIBUTION										
NE	0.49	0.49	0.41	0.41	6.[illegible]	5.92	1.05	0.95	1.91	1.80
NC	0.49	0.49	0.41	0.41	6.14	5.86	1.04	0.94	1.89	1.78
S	0.44	0.44	0.37	0.3[illegible]	5.64	5.39	0.96	0.86	1.74	1.64
W	0.49	0.49	0.41	0.41	6.14	5.86	1.04	0.94	1.89	1.78
DOMESTIC WATER HEATING EQUIPMENT										
NE	0.08	0.08	0.10	0.14	0.09	0.11	0.11	0.12	0.23	0.25
NC	0.08	0.08	0.10	0.14	0.09	0.11	0.11	0.12	0.23	0.25
S	0.08	0.08	0.10	0.14	0.09	0.11	0.11	0.12	0.23	0.25
W	0.08	0.08	0.10	0.14	0.09	0.11	0.11	0.12	0.23	0.25
WATER DISTRIBUTION AND FIXTURES										
NE	0.95	0.98	1.16	1.20	1.68	1.72	1.12	1.15	1.50	1.55
NC	0.98	1.01	1.19	1.24	1.73	1.77	1.15	1.18	1.55	1.60
S	0.87	0.90	1.06	1.10	1.54	1.57	1.02	1.05	1.37	1.42
W	0.98	1.01	1.19	.124	1.73	1.77	1.15	1.18	1.55	1.60

*Cost to the owner, e.g., includes contractor's overhead and profit; regionally adjusted.

SOURCE: Kling-Lindquist, Inc.; Arthur D. Little, Inc., estimates.

TABLE IV-4

ESTIMATED CHANGE IN UNIT COST* OF CONVENTIONAL VS. ASHRAE 90 MODIFIED

(Dollars per Sq. Ft. of Floor Space)

	Northeast	North Central	South	West	Unwei
Single-Family Residence	+0.01	-0.04	-0.04	+0.01	
Multi-Family, Low Rise	-0.45	-0.54	-0.28	-0.36	
Office Building	-0.35	-0.29	-0.94	-0.93	
Retail Stores	-0.11	+0.04	-0.32	-0.33	
School	-0.56	-0.39	-0.46	-0.33	

---

*Cost to the owner; regionally adjusted.

SOURCE: Arthur D. Little, Inc.

TABLE IV-4

ED CHANGE IN UNIT COST* OF CONVENTIONAL VS. ASHRAE 90 MODIFIED BUILDINGS

(Dollars per Sq. Ft. of Floor Space)

	Northeast	North Central	South	West	Unweighted Average
ce	+0.01	-0.04	-0.04	+0.01	-0.02
e	-0.45	-0.54	-0.28	-0.36	-0.41
	-0.35	-0.29	-0.94	-0.93	-0.63
	-0.11	+0.04	-0.32	-0.33	-0.18
	-0.56	-0.39	-0.46	-0.33	-0.44

egionally adjusted.

ttle, Inc.

	Change in Cost (Dollars Per Square Foot Floor Area)
Exterior Walls	+ 0.33
Exterior Glass	+ 0.24
Roof	+ 0.15
HVA/C Equipment	- 0.39
HVA/C Distribution	- 0.48
HVA/C Controls	+ 0.12
Lighting	- 0.04
Electrical Distribution	- 0.28
Domestic Water Heating	+ 0.02
Hot Water Distribution	+ 0.04
Net Change	- 0.29

In general, the application of ASHRAE 90 increases the unit cost of the exterior wall, floors, and roof due to more insulation, and other modifications which improve thermal performance. The cost of domestic water heating systems also increase slightly due to equipment modifications and additional pipe insulation. The cost of glass may be higher under ASHRAE 90 due to the use of insulating glass or, in fact, may be lower as less glass area is allowed. In several cases, these costs were offsetting, such that an ASHRAE 90 modified (double-glazed) building actually cost less than a conventional (single-glass) building on a unit area basis. The cost of lighting is reduced slightly (lamp fixtures), while that of electrical distribution increases due to more switching. The unit cost of HVA/C system controls also increases in certain cases.

Virtually all of the above increases in cost were offset by the cost reductions which occur in the HVA/C system. This occurs as a savings in both central plant equipment (boiler, chiller, etc.) and in the HVA/C distribution system (delivery fans, pumps, ducts, etc.). These reductions are on the order of a 10 to 15% cost savings for every 30% reduction in system capacity.

Note that of the twenty prototypical buildings, only three showed an increase in capital cost. In fact, the remaining seventeen ASHRAE 90 modified buildings cost from $0.04 to $0.94 less per square foot.

The greatest impact was found to be in the nonresidential sector, particularly in the office buildings ($0.63 per square foot average savings). Effects on the initial cost of single-family residences due to ASHRAE 90 were found to be minimal.

Table IV-5 expresses the changes in unit costs as a percent of the total cost of buildings similar to those which were investigated. Savings range from 0.1% to 2.1% of the total cost, not large to say the least, but still less than the cost of conventional buildings. As will be shown later, these cost reductions will be somewhat offset by increased design fees, although the application of ASHRAE 90 need not increase total initial building costs to the owner.

ADL concludes that the application of ASHRAE 90 (exclusive of additional design services) would probably result in slightly lower initial costs for buildings, as the cost of improving a building's thermal performance is comparatively low and is offset by the savings realized in HVA/C equipment and distribution systems. However, the overall building cost impact is so minimal (less than 2% maximum savings) that allowing for slight errors in estimating, it would be safe to assume that the ASHRAE 90 modified buildings would cost roughly the same as their conventional counterparts.

Finally, this is contrary to what members of the construction industry believe in general, and certain parties believe in particular. While cost data on recent and pending projects which are being designed under rigorous energy conservation guidelines is generally lacking, several building owners have undertaken studies to investigate the possibility of having both lower-capital costs and lower operating costs. For the most part, they have concurred that this may well be the case. It may be anticipated that this will be further confirmed as ASHRAE 90, or similar state standards, gain in usage.

D. OPERATING COST IMPACT OF THE ENERGY AUGMENTATION APPROACH

Using the fuel costs of Table IV-1, annual energy savings were also derived for each prototypical building with an "optimum" sized solar system. Table IV-6 summarizes the annual savings in dollars per square foot, and the percent reduction these savings represent over energy costs for the conventional building.

The general magnitude of these savings is not significant when compared to those savings obtainable under the standard/prescriptive approach.

E. INITIAL COST IMPACT OF THE ENERGY AUGMENTATION APPROACH

Unlike the prescriptive-performance approach, the use of solar systems for water and space heating results in an incremental increase in initial

TABLE IV-5

IMPACT OF ASHRAE 90 MODIFICATIONS ON BUILDING COST

(1975 Dollars per Sq. Ft.)

	Typical Project Cost[1]		
	Range	Median	Average Change in Cost Due to ASHRAE 90
Single-Family Residence	16.00-24.00	20.00	-0.02
Low-Rise Apartments	14.00-28.00	19.50	-0.41
Office Building	22.00-43.00	32.00	-0.63
Retail Store	12.00-21.00	17.00	-0.18
School Building	20.00-40.00	30.00	-0.44

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[1] For projects similar to prototypical buildings analyzed.

SOURCE: Arthur D. Little, Inc., estimates.

TABLE IV-5

IMPACT OF ASHRAE 90 MODIFICATIONS ON BUILDING COST

(1975 Dollars per Sq. Ft.)

Typical Project Cost[1]		Average Change in Cost Due to ASHRAE 90	Change in Median Cost (Percent)
Range	Median		
16.00-24.00	20.00	-0.02	-0.1
14.00-28.00	19.50	-0.41	-2.1
22.00-43.00	32.00	-0.63	-2.0
12.00-21.00	17.00	-0.18	-1.1
20.00-40.00	30.00	-0.44	-1.5

o prototypical buildings analyzed.

le, Inc., estimates.

TABLE IV-6

ENERGY AUGMENTATION APPROACH, ANNUAL SAVINGS IN ENERGY COST

(Dollars per Square Foot and Percent Reduction)

	Northeast	North Central	South
Single-Family Residence	0.078 (9%)	0.043 (12%)	0.098 (20%)
Low Rise Apartment	0.125 (8%)	0.059 (13%)	0.050 (10%)
Office Building	0.090 (6%)	0.049 (6%)	0.044 (6%)
Retail Store	0.136 (5%)	0.108 (6%)	0.081 (5%)
School	0.056 (7%)	0.029 (7%)	0.023 (6%)

SOURCE: Arthur D. Little, Inc., estimates.

TABLE IV-6

GY AUGMENTATION APPROACH, ANNUAL SAVINGS IN ENERGY COST

(Dollars per Square Foot and Percent Reduction)

Northeast	North Central	South	West
0.078 (9%)	0.043 (12%)	0.098 (20%)	0.153 (23%)
0.125 (8%)	0.059 (13%)	0.050 (10%)	0.043 (10%)
0.090 (6%)	0.049 (6%)	0.044 (6%)	0.031 (5%)
0.136 (5%)	0.108 (6%)	0.081 (5%)	0.062 (5%)
0.056 (7%)	0.029 (7%)	0.023 (6%)	0.018 (5%)

e, Inc., estimates.

building cost. Table IV-7 shows that these increased costs range from $0.04 to $0.88 per square foot, which in turn are between 0.2% to 4.2% of the initial project cost.

The singular most critical variable of these costs is the cost of the solar systems, and while it is not our intention to give a detailed cost breakdown, some briefing is needed.

The cost of solar systems was based on near-term hydronic system configuration and equipment design, and is indicative to a large extent on field-installed systems without benefit of extensive product engineering. The specific elements on which the costing analysis was structured included:

- Solar Collector
- Heat Transfer Fluid
- Insulated Water Tanks (for thermal storage) and
- Pumps, valves, heat exchangers, piping, controls, etc. for the solar loop.

Our estimates on solar collector cost--a key component--were based upon a manufacturing operation capable of an annual volume of 500,000 units at 15 square feet per unit.

The installed cost for the baseline solar collector alone used in this analysis (two panes over a flat black absorber) were assumed to be about $7 a square foot. For very large systems, the installed cost of the solar collector was the controling cost, whereas for very small systems, it was the cost of other items such as storage tanks, heat exchangers, and controls. For some of the very large systems (above 10,000 square feet), the total system cost could be less than $10 per square foot, seventy percent of which would be accounted for by the installed solar collector costs. In the intermediate range, say about 1,000 square feet, total system costs are somewhat over $11 a square foot, and storage begins to become an important cost element--being about 25% of total system cost. For very small systems (i.e., less than 100 square feet), total system costs may be in excess of $20 per square foot, and the cost per unit area increases rapidly as system cost is reduced. In this size range, thermal storage, heat exchangers, pumps and piping and controls are all important cost elements.

TABLE IV-7

UNIT COSTS OF "OPTIMUM" SOLAR ENERGY SYSTEMS FOR PROTOTYPICAL BUILDINGS

(Dollars per sq. ft. of Floor Area)

	Northeast		North Central		South	
	DHW[1]	DHW/H[2]	DHW	DHW/H	DHW	DHW/H
Single-Family Residence	0.98	0.68	0.28	0.58	0.37	0.42
Low-Rise Apartment Building	0.70	0.72	0.44	0.62	0.70	0.82
Office Building	0.14	0.43	0.09	0.42	0.16	0.39
Retail Store	0.06	0.18	0.04	0.14	0.07	0.11
School	0.23	0.29	0.15	0.25	0.27	0.33

---

1. Domestic hot water system.
2. Domestic hot water and space heating system.

SOURCE: Arthur D. Little, Inc.

TABLE IV-7

PTIMUM" SOLAR ENERGY SYSTEMS FOR PROTOTYPICAL BUILDINGS

(Dollars per sq. ft. of Floor Area)

rtheast	North Central		South		West	
DHW/H[2]	DHW	DHW/H	DHW	DHW/H	DHW	DHW/
0.68	0.28	0.58	0.37	0.42	0.36	0.72
0.72	0.44	0.62	0.70	0.82	0.55	0.59
0.43	0.09	0.42	0.16	0.39	0.10	0.31
0.18	0.04	0.14	0.07	0.11	0.05	0.14
0.29	0.15	0.25	0.27	0.33	0.18	0.24

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ting system.

CHAPTER V

IMPACT OF ASHRAE 90 ON NATIONAL ENERGY CONSUMPTION IN RESIDENTIAL AND COMMERCIAL BUILDINGS

A. INTRODUCTION

Based upon the calculated savings in annual energy consumption for the prototypical buildings discussed in Chapter III, it is possible to estimate the aggregate effect which ASHRAE 90 would have on the nation's energy demand in buildings.

The initial step is to establish the amount of annual energy consumed domestically in residential and commercial buildings. Along with a baseline projection of changes in energy consumption over the period 1975-1990, estimates of energy usage were based upon ADL's report to CEQ and FEA entitled, "*Residential and Commercial Energy Use Patterns, 1970-1990,*" (*November, 1974*). Certain appropriate parts of the report are summarized here along with key assumptions. However, the reader is referred to the original report for a more detailed discussion of the approach and methodology used in estimating both benchmark energy consumption and baseline growth projections.

B. ANNUAL ENERGY DEMAND IN BUILDINGS, 1975

The Continental United States consumed approximately 17.4 quads[1] of energy in the residential and commercial building sectors in 1975 (see Table V-1). Of this total, 12.5 quads were consumed in the residential sector and 4.2 quads in the commercial sector. The total for the commercial sector excludes 0.6 quads of energy which is classified as "unallocated commercial." This amount is not affected by ASHRAE 90 and is projected to grow at real GNP rates, 3.9% annually, over the 1975-1990 period.

Unless otherwise noted, all estimates of energy consumption in this chapter are measured at the building boundary. An alternative method is to include power plant and distribution losses. In this case, electricity is converted at 10,000 Btu per kwh rather than 3,413 Btu per kwh, to allow for inefficiency at the power plant. Figures V-1 and V-2 show 1970 energy demand in construction by end use under each method. While these graphs clearly show the extent to which demand is understated under the building boundary method, this assumption is appropriate for a demand anlysis because it does not raise the issue of power plant fuel or efficiency, which properly belongs in a supply analysis.

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[1] quad = 10^{15} Btu.

Table V-1

ANNUAL ENERGY DEMAND BY BUILDING TYPE, 1975 - 90
(Trillions of Btu)

	1975	1980	1985
Residential			
Mobile Homes	419	628	727
Single-Family Detached	9,370	10,172	10,838
Low Density	1,772	1,875	1,980
Multi-Family, Low Rise	631	673	756
Multi-Family, High Rise	390	404	431
Total	12,582	13,752	14,732
Commercial			
Office Buildings	809	1,002	1,280
Retail Establishments	904	1,150	1,513
Schools	892	985	1,105
Hospitals	486	593	691
Other	1,078	1,235	1,386
Total	4,169	4,965	5,975
Unallocated Commercial	629	748	905
Grand Total	17,380	19,465	21,612

SOURCE: "Residential and Commercial Energy Use Patterns, 1970 - 1990," Arthur D. Little, Inc., November, 1974.

Table V-1

ANNUAL ENERGY DEMAND BY BUILDING TYPE, 1975 - 90

(Trillions of Btu)

	1975	1980	1985	1990
	419	628	727	811
ched	9,370	10,172	10,838	11,611
	1,772	1,875	1,980	2,081
Rise	631	673	756	817
Rise	390	404	431	449
	12,582	13,752	14,732	15,769
	809	1,002	1,280	1,636
nts	904	1,150	1,513	1,969
	892	985	1,105	1,228
	486	593	691	791
	1,078	1,235	1,386	1,698
	4,169	4,965	5,975	7,322
cial	629	748	905	1,098
	17,380	19,465	21,612	24,189

nd Commercial Energy Use Patterns, 1970 - 1990,"
ittle, Inc., November, 1974.

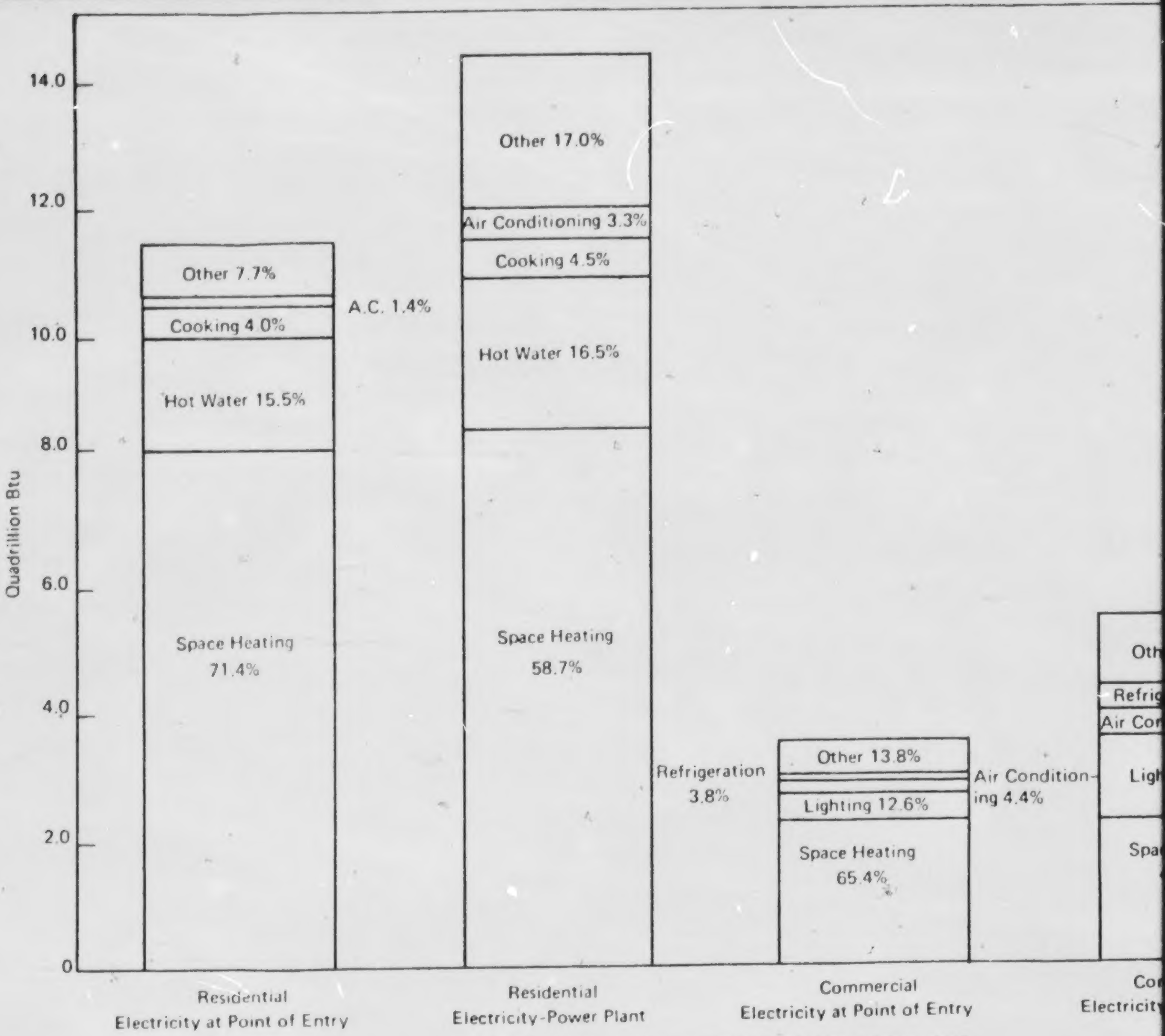


FIGURE V–1 1970 ENERGY DEMAND BY END USE

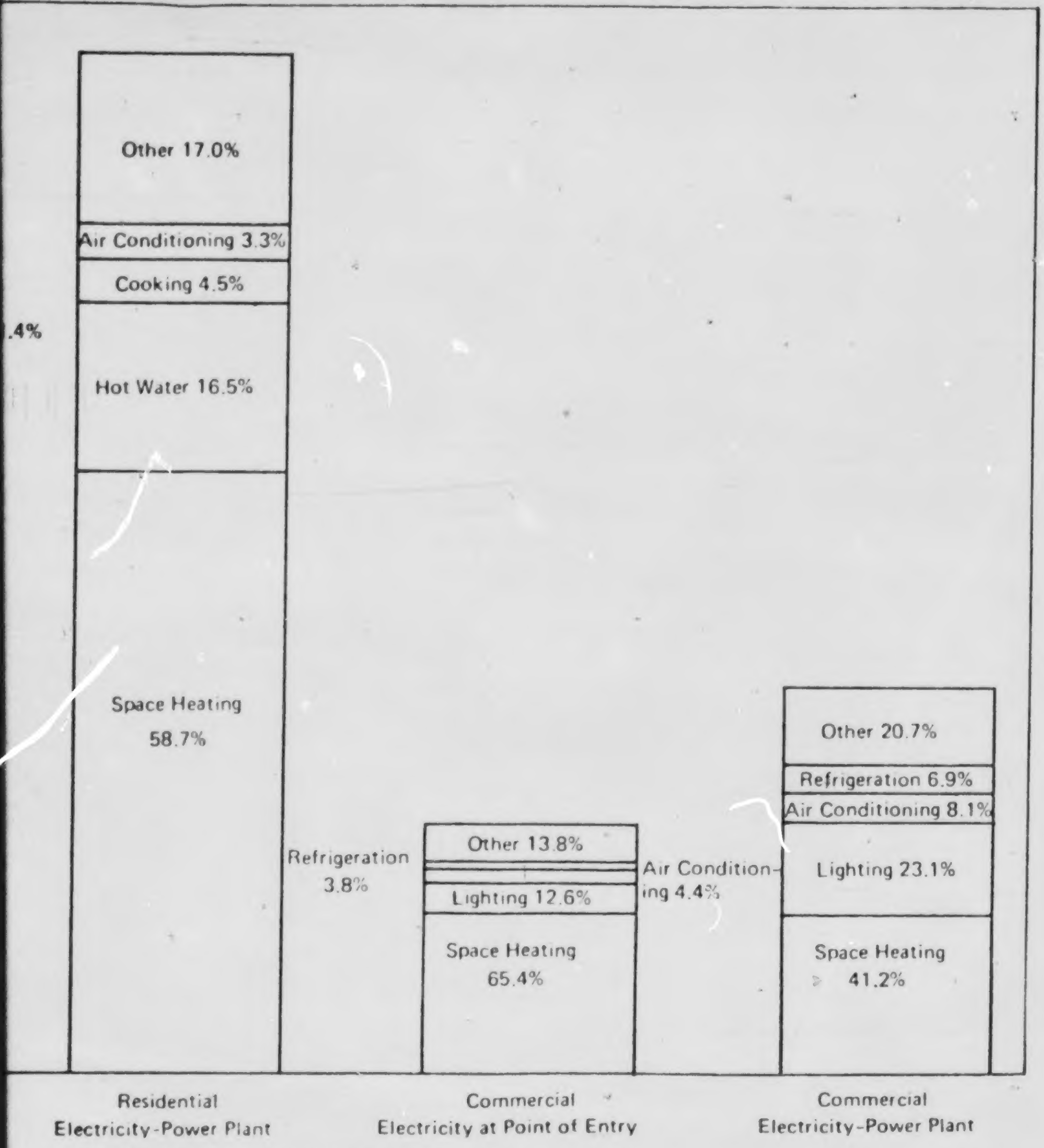


FIGURE V–1 1970 ENERGY DEMAND BY END USE

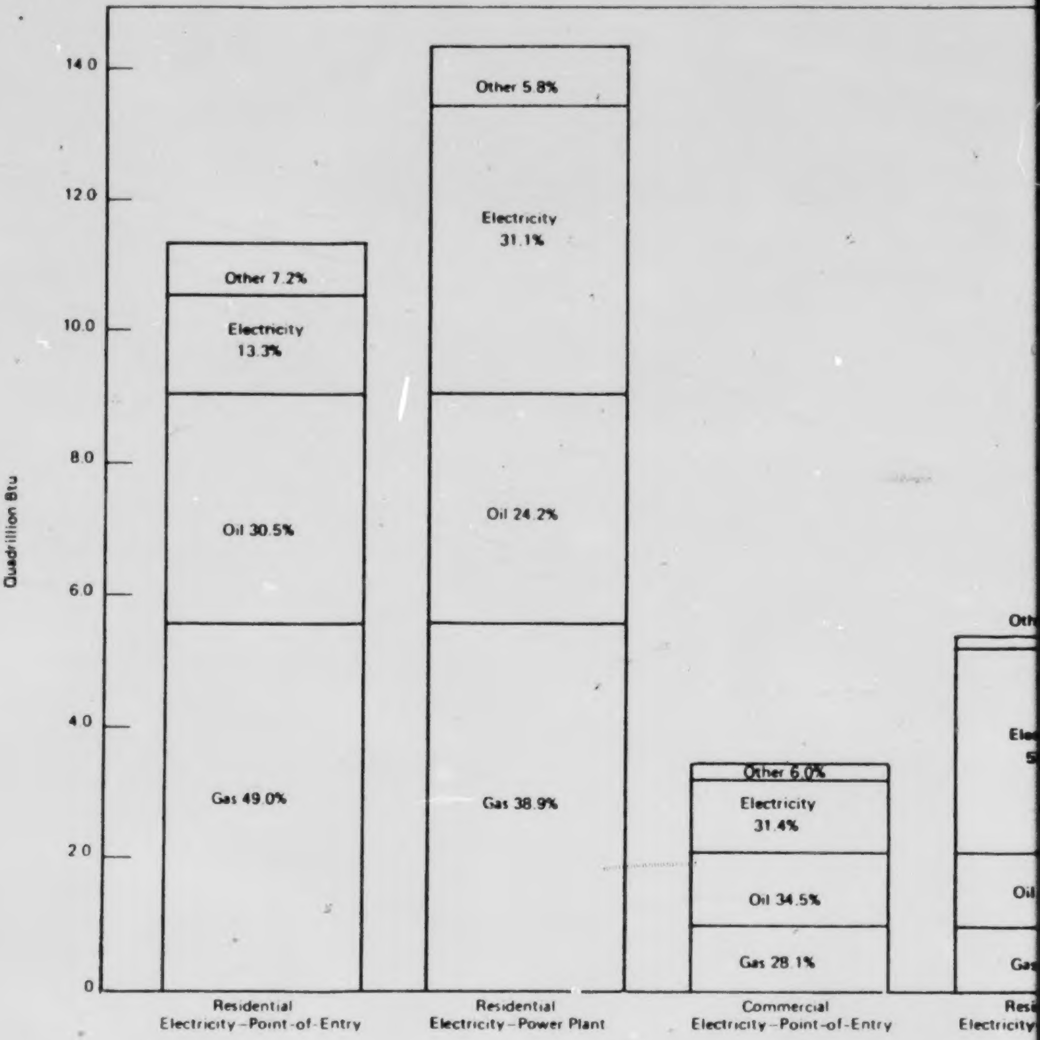


FIGURE V–2 1970 ENERGY DEMAND BY FUEL TYPE

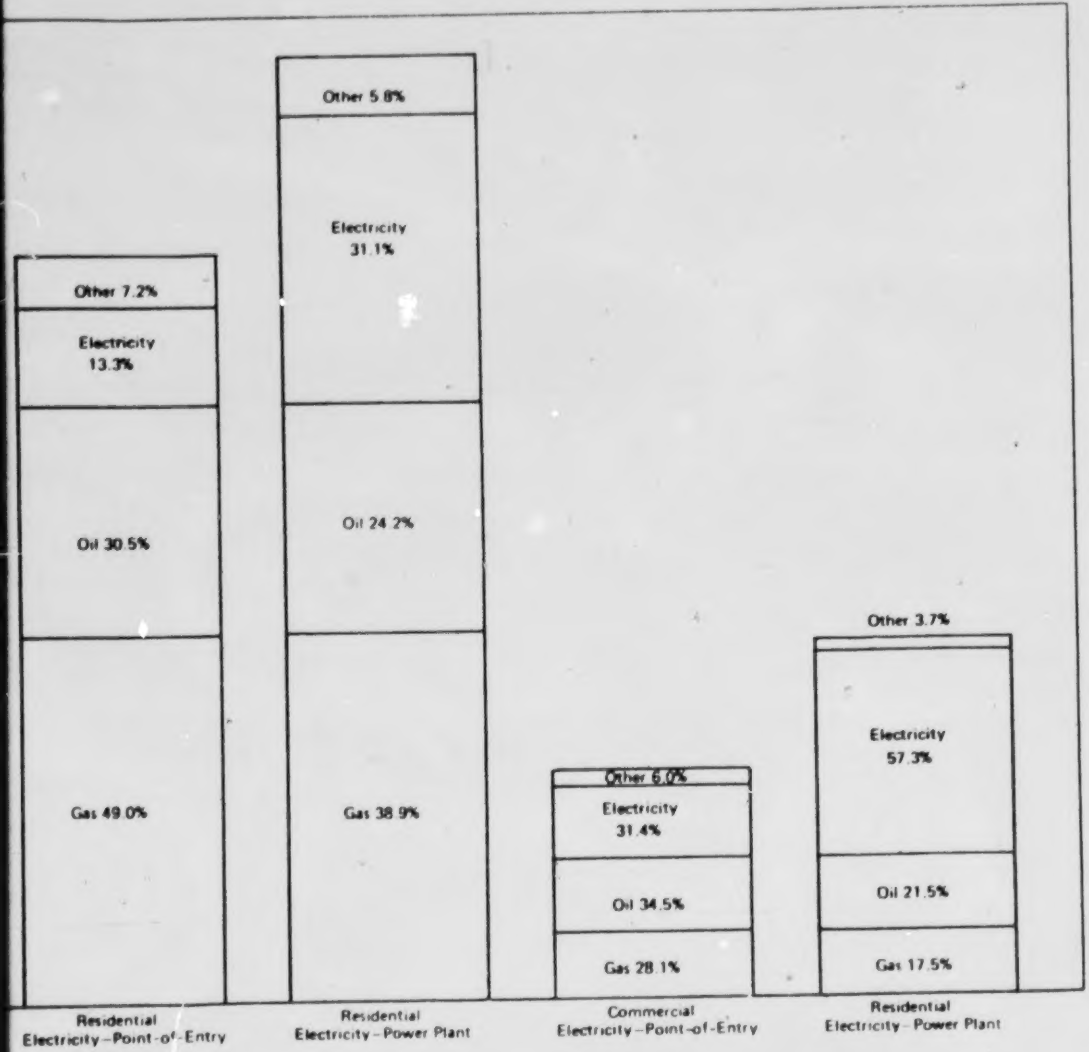


FIGURE V–2 1970 ENERGY DEMAND BY FUEL TYPE

Two significant conclusions can be drawn from Table V-1 and Figure V-1. First, the residential sector, with 72% of the energy demand at point of consumption, is the major end user. Second, space heating requirements dominant in both sectors, account for approximately 69% of the total energy used.

Figure V-3 shows 1970 energy demand by region. It is clear the four Census regions have grossly different fuel consumption patterns, which emphasizes the problem of finding universal solutions to the energy conservation puzzle.

C. GROWTH IN ANNUAL ENERGY DEMAND

From 1975 to 1990, ADL projects that U.S. energy consumption in residential and commercial buildings will grow from 17.4 quads to 24.2 quads, an annual compounded growth rate of 2.3% (Figure V-4). This growth rate does not include efficiency losses incurred by the power plant in the generation, transmission, and distribution of electricity. Inclusion of such losses would increase the overall growth rate to about 3.2% per year.

As shown in Table V-1, annual energy consumption in the residential sector is expected to grow at 1.5% per year, from 12.6 quads in 1975 to 15.8 quads in 1990. Consumption in the commercial sector is expected to grow at 4.8% per year, from 4.2 quads in 1975 to 8.4 quads in 1990 (excluding a growth from 0.6 quads to 1.1 quads for the "unallocated commercial" portion).

Historical data on energy consumption for the combined sectors indicate that the annual rate of growth during the period 1950-1970 was 4.3%. ADL is, therefore, predicting significant differences from past trends. Other analyses that have used these historical data as a key variable are predicting a continuation of high growth rates, in the neighborhood of 3.5-4.0% per year.

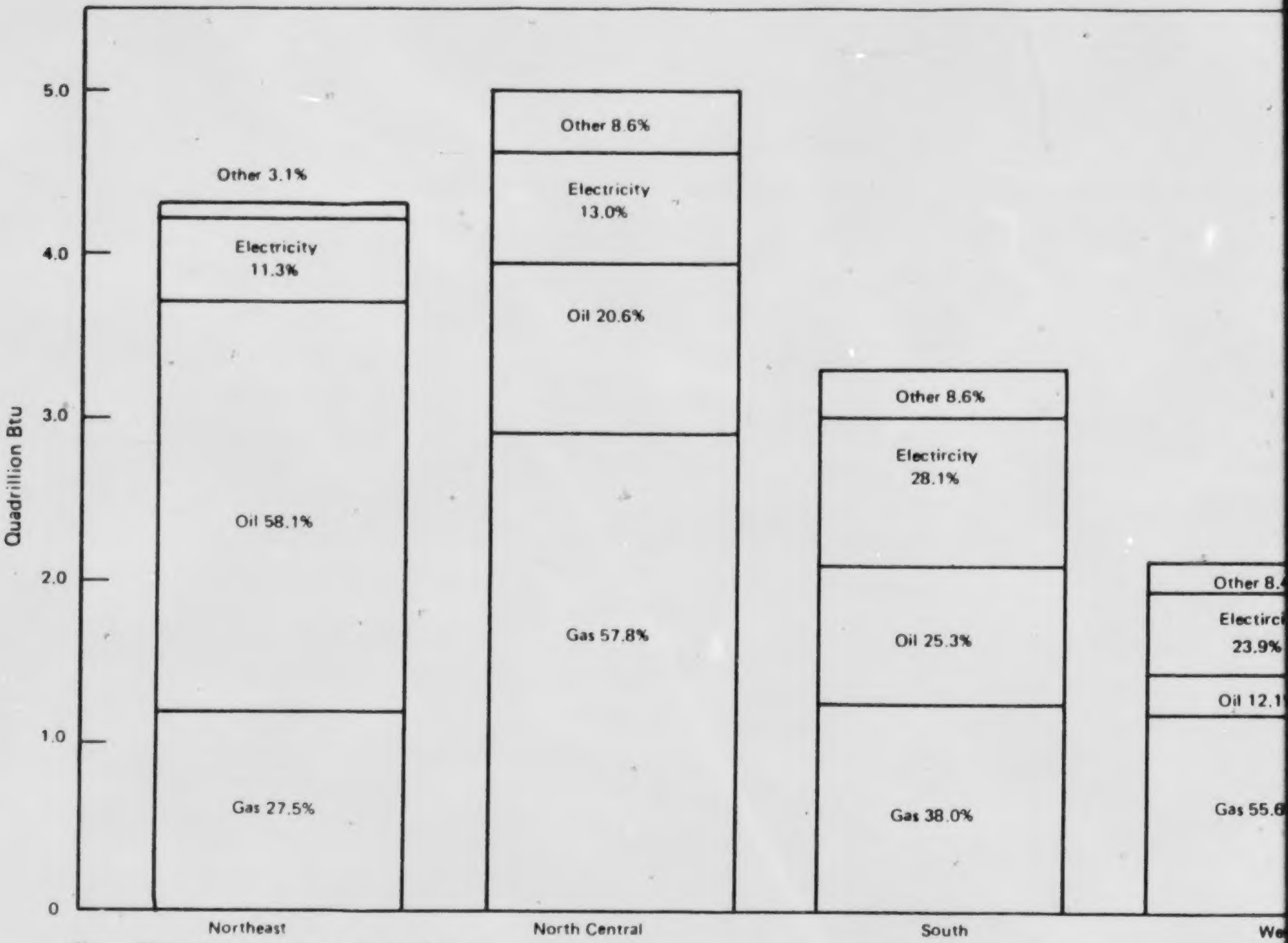
Table V-2 details energy consumption for the combined sectors from 1950-1990 in ten-year intervals, with average annual growth rates. Some deceleration of growth was experienced in the decade of 1960-1970. Our projections show a continuation of this flattening trend, although at a more rapid rate than would be predicted by time trend analyses.

TABLE V-2

RESIDENTIAL AND COMMERCIAL ENERGY CONSUMPTION, 1950-1990

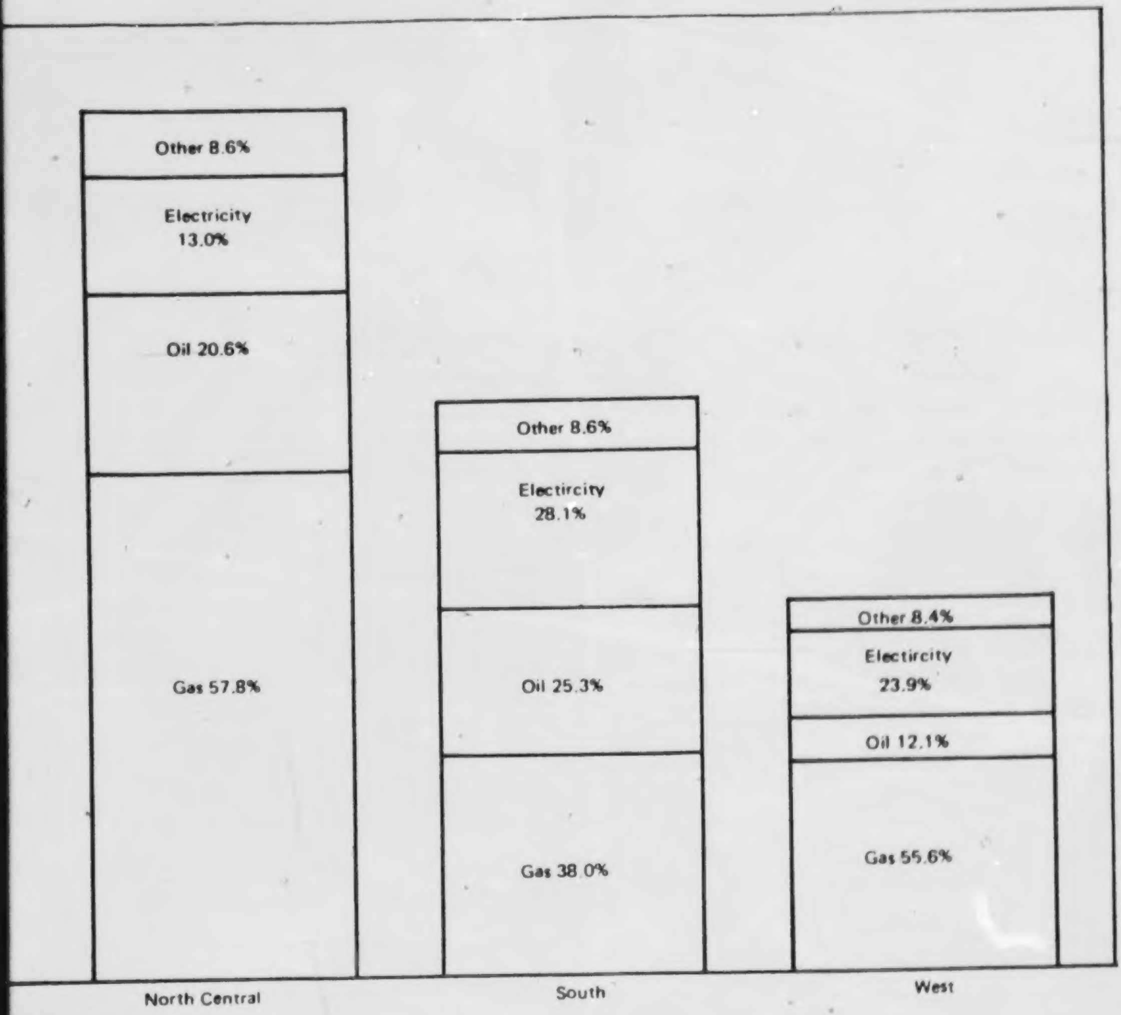
	1950		1960		1970		1980		1990
Total Residential and Commercial Energy Usage (quads)	6.6		10.2		15.3		19.5		24.2
Average Annual Growth Rates		4.6%		4.1%		2.4%		2.2%	

SOURCES: Bureau of Mines and Arthur D. Little, Inc., estimates.



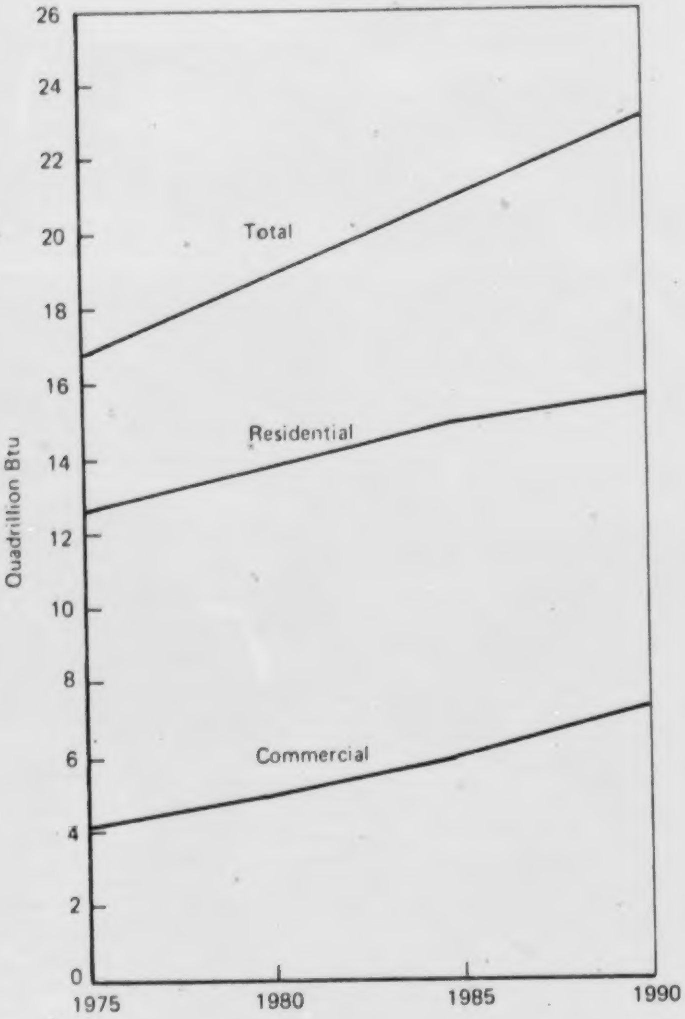
Note: Electricity measured at point-of-entry.

FIGURE V–3 1970 ENERGY DEMAND BY FUEL TYPE AND REGION



-of-entry.

FIGURE V–3 1970 ENERGY DEMAND BY FUEL TYPE AND REGION



Note: Electricity measured at point-of-entry.

Source: Arthur D. Little, Inc.

FIGURE V–4 ENERGY GROWTH IN THE RESIDENTIAL AND COMMERCIAL SECTORS, 1975–1990

It is interesting that commercial energy demand is expected to grow at almost the same rate as GNP (4.0% versus 3.9%). This suggests that whether the "unallocated commercial" portion is overstated or understated, the estimated final energy growth rate is virtually unaffected.

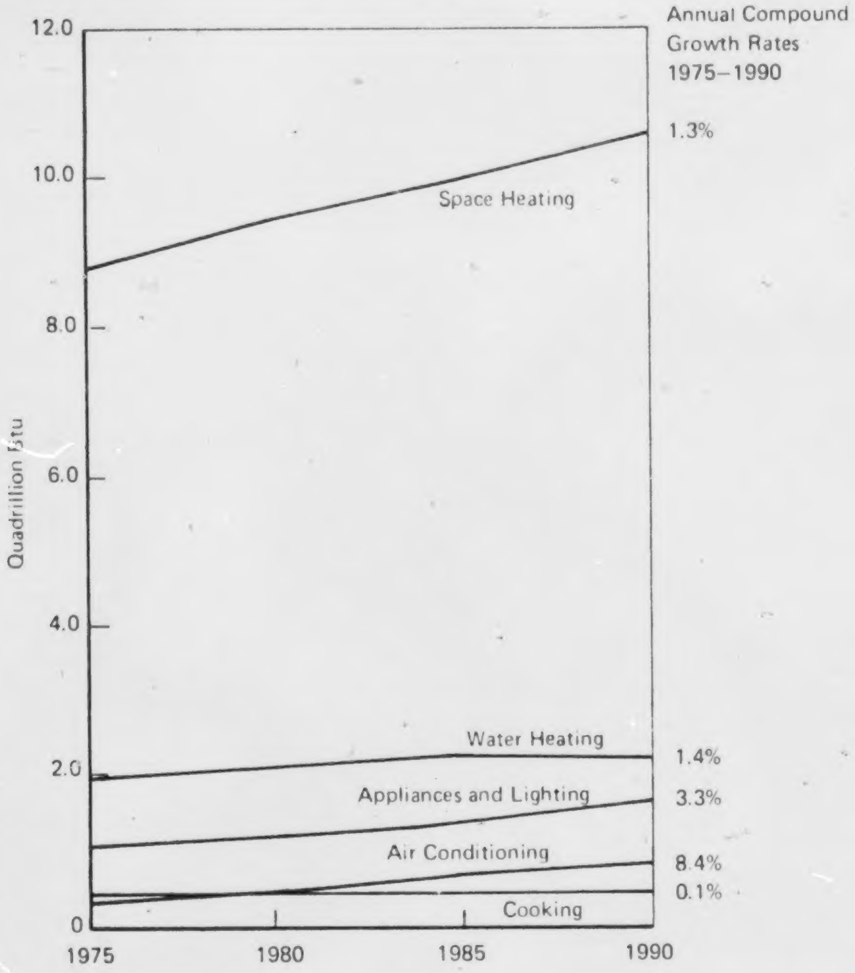
Figures V-5 and V-6 depict the growth of the various end uses for energy in each of the sectors. They reflect not only the anticipated high rates of growth in the auxiliary loads and air conditioning, but also the dominance of space heating, which is expected to continue. Although space heating will continue to be the primary consumer, its relatively low rate of growth will dampen considerably the overall growth rates. Particularly significant is the projection of a 1.3% annual growth rate for residential space heating. Because the total number of occupied units in the inventory is expected to grow at an annual rate of 1.8%, the analysis implies that per-unit consumption for residential space heating will gradually decline by 9% over the next 20 years.

Data on per-unit consumption over the past 20 years are not readily available, but a very rough analysis, using stated total residential and commercial consumption for 1950, and the limited amount of data available on appliance and air conditioning saturations in 1950, leads to the belief that per-unit energy consumption of residential space heating increased by 37% over the 1950-1970 period. This contrasts significantly with the projection of a 9% decrease in per-unit consumption over the next 20 years.

This phenomenon has been broken down into the components of change in per-unit energy consumption for 1950-1970 and 1970-1990. Historically, the major factors which appear to have contributed to the rapid growth in consumption of energy for heating in the residential sector over the past 20 years are the shift in house size and type, the fuel used, and the mix in heating systems between central systems and room space heaters. The major contributors to a decrease in per-unit demand through 1990 are shifts in fuel mix and improvements in technology and use patterns.

The bases for the projections in energy demand over the period 1975 to 1990 are as follows:

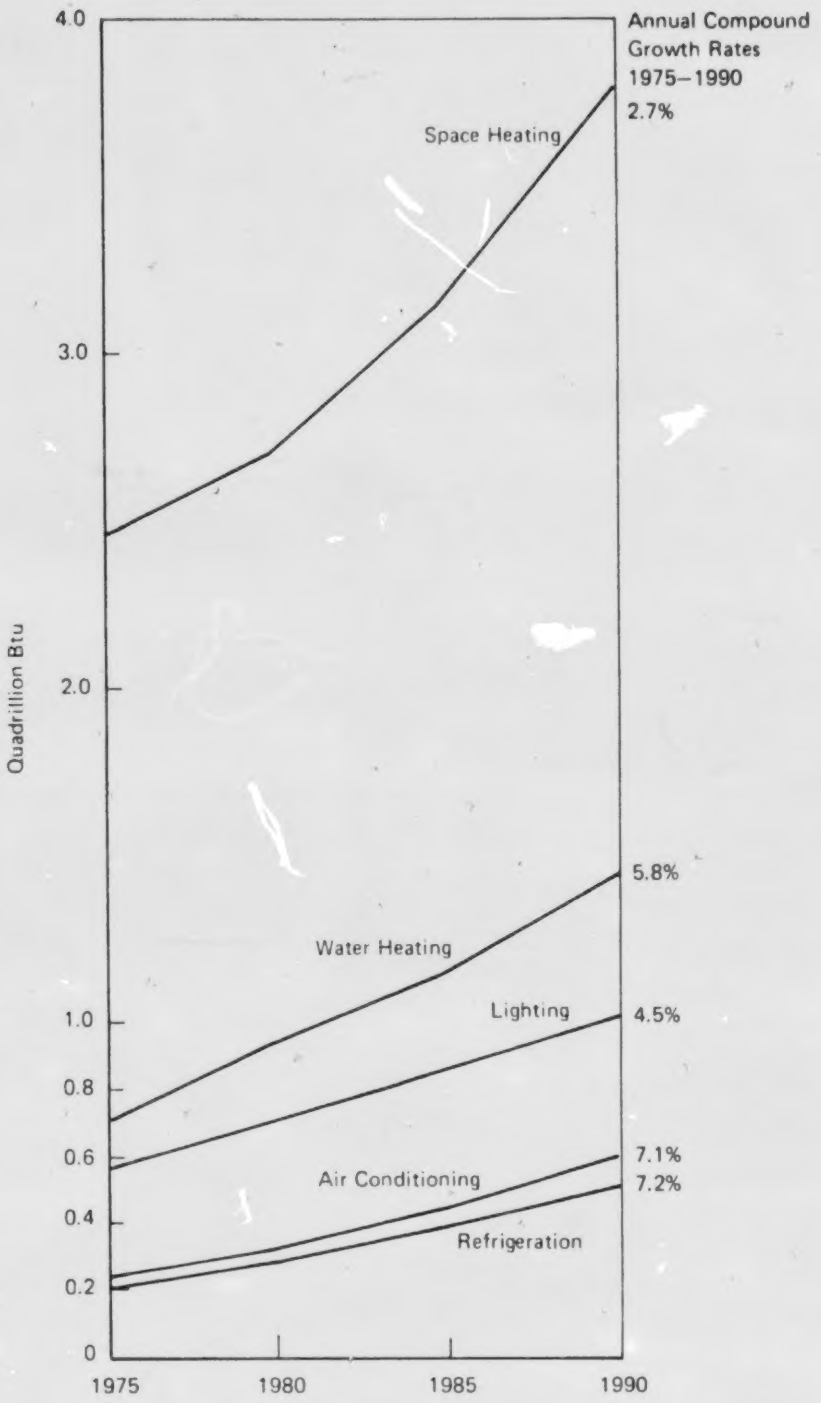
- *House Size and Type:* A continued increase, as old single-family units at an average size of 1,300 square feet are replaced with new units approaching, and sometimes exceeding, 1,600 square feet. This increase will be smaller than for the preceding period because of decreased family size, a shift to higher-density units, increased land costs, and lack of available land for larger structures.
- *House Location:* A continuation of the shift of homes from the colder Northeast and North Central regions to the South and the West.



Note: Electricity measured at point-of-entry.

Source: Arthur D. Little, Inc.

FIGURE V–5 GROWTH IN RESIDENTIAL ENERGY DEMAND BY END USE, 1975–1990



Note: Electricity measured at point-of-entry.

Source: Arthur D. Little, Inc.

FIGURE V–6 GROWTH IN COMMERCIAL ENERGY DEMAND BY END USE, 1975–1990

- *House Thermal Efficiency:* A reversal of the slight decrease in efficiency experienced in the past, with an assumed 3% improvement in the efficiency of the average homes over the period 1970 to 1990. This improvement consists of an average 1-2% for existing homes and 4% for new homes.

- *House Fuel Used:* Over the past 20 years, this factor has led to increased consumption, primarily because wood-burning and nonheated homes have been replaced by homes heated with conventional fuel. Over the next 20 years, the increase in penetration of electric heat from 8% to 20% will mean a 7% decrease in per-unit consumption (at the point of consumption because of electricity's greater efficiency).

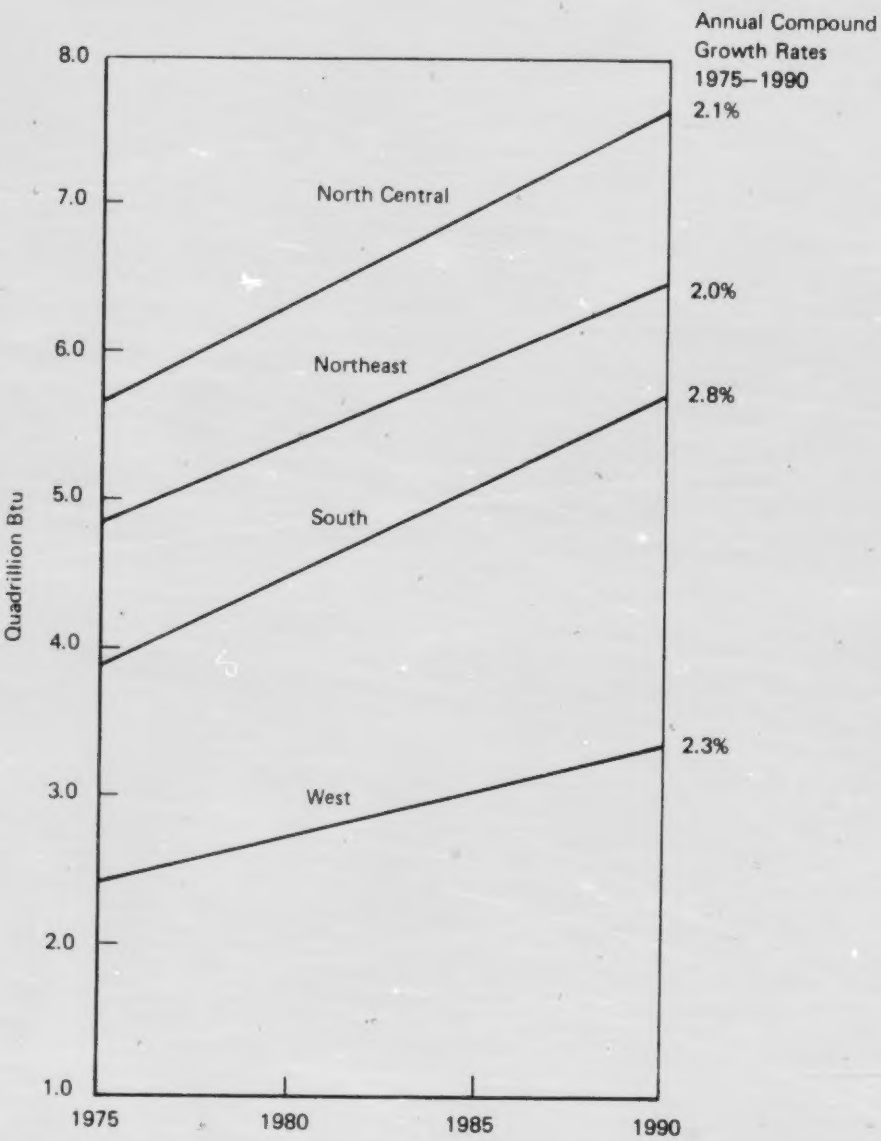
- *Heat System Technology:* Projected minor improvements in heating systems have been projected to reducing energy demand by 1% over the 1975-1990 period. It was assumed that virtually all new electrically heated homes being built by 1990 will employ a heat pump rather than an electric furnace. On average, the heat pump consumes only 60% of the electrical energy demand of a conventional electrically heated house.

- *Consumer Energy Conservation "Ethic":* A continuation of the energy conservation ethic which has developed over the recent two years was assumed although its effect will be significantly below the full potential. This will result in a savings of nearly 2% on unit consumption over the 1975-1990 period for both new and existing homes.

- *Heat System Mix:* Over the 1950-1970 period, there was a major replacement of room heating systems, which consume less energy, with central heat. This shift seems to have accounted for over half of the unit growth over this period. While this trend will continue, it will abate, because homes in some areas with minor heating loads (deep South) will continue to use noncentral systems. The effect over the next 20 years will be to increase unit consumption by 4%.

To put the impact of these changes on the unit demand in perspective, the effect on energy demand in 1990 was analyzed using the 1990 inventory and fuel distribution and the 1970 unit demands. With these assumptions, energy demand is 24.7 quads in 1990, which represents a growth rate of 2.4% per year. This growth rate is only slightly higher than the base case growth rate of 2.3% and suggest that while the assumptions regarding technical improvement and a conservation ethic might be slightly optimistic, these assumptions do not affect the growth rate significantly.

Figure V-7 shows energy projections on a regional basis and from this figure it is clear that regional growth is reasonably similar with the South having the highest annual growth rate at 2.8% and the Northeast the slowest at 2%.



Note: Electricity measured at point-of-entry.

Source: Arthur D. Little, Inc.

FIGURE V–7 GROWTH IN ENERGY DEMAND BY REGION, 1975–1990

D. IMPACT OF ASHRAE 90

The reduction in energy demand attributable to the adoption of ASHRAE 90 would increase over time as the annual energy consumed by those buildings built after 1975 increases as a percent of the total energy consumed in existing buildings. Likewise, maximum potential energy savings could only be realized if the document were adopted and enforced by all code authorities. A somewhat lesser reduction is more probable depending upon how many states adopt ASHRAE 90 or some similar standard.

Table V-3 shows the annual energy demand by buildings constructed after 1975. By 1980, this would total about 3.4 quads, or 17% of total annual consumption. By 1990, this would increase to 10.6 quads, or 44% of total demand. Thus, the earlier ASHRAE 90--or some similar document--is adopted by the industry, the greater the potential annual savings achievable in any future year.

The first step in evaluating ASHRAE 90's impact is to estimate the maximum percentage reduction of the estimates shown in Table V-3 if the standard were to be adopted by all states beginning in 1976. This was determined based upon the computer simulation done for each of the prototypical buildings. The five building types selected represent a significant percentage of total annual consumption:

Sector	Building Type Analyzed	Percent of Sector Consumption, 1975
Residential	Single-family Residence Multi-Family Low-Rise	87
Commercial	Office Building Retail Store School	66

For those building types not analyzed, assumptions were made as to the likely reduction possible under ASHRAE 90, based upon an interpretation of their construction and usage characteristics. Low-density (2 to 4 units) were assumed to have the same reduction as the single-family residence. Reductions in the low-rise apartment building were also assumed to apply to high-rise multi-family buildings. Hospitals, being an "institutional" building and an energy requirement which is probably less susceptible to ASHRAE 90 due to medical and life support considerations, were assumed to have potential reductions on the order of 75% of those possible for school buildings. Reductions in "other" nonresidential buildings were assumed to be the unweighted average of the office, retail store, and school buildings.

The maximum savings possible by the implementation of ASHRAE 90 are shown in Table V-4. It is estimated that 0.8 quads of energy could be

TABLE V-3

ANNUAL ENERGY DEMAND BY BUILDINGS CONSTRUCTED AFTER 1975

(Trillions of Btu)

	1975	1980	1985
Residential			
Mobile Homes	0	282	493
Single-Family Detached	0	1,502	2,808
Low Density	0	345	696
Multi-Family, Low-Rise	0	131	283
Multi-Family, High-Rise	0	67	150
Total	0	2,327	4,430
Commercial			
Office Buildings	0	241	584
Retail Establishments	0	307	743
Schools	0	153	338
Hospitals	0	139	273
Other	0	229	459
Total	0	1,069	2,397

SOURCE: Arthur D. Little, Inc. Estimates

TABLE V-3

ANNUAL ENERGY DEMAND BY BUILDINGS CONSTRUCTED AFTER 1975
(Trillions of Btu)

	1975	1980	1985	1990
	0	282	493	697
ached	0	1,502	2,808	4,116
	0	345	696	1,026
-Rise	0	131	283	403
h-Rise	0	67	150	214
	0	2,327	4,430	6,456
	0	241	584	1,031
ents	0	307	743	1,305
	0	153	338	545
	0	139	273	421
	0	229	459	878
	0	1,069	2,397	4,180

tle,Inc. Estimates

TABLE V-4

ANNUAL ENERGY SAVINGS POSSIBLE BY ADOPTION OF ASHRAE 90 BY ALL STATES

(Trillions of Btu)

	1975	1980	1985
Residential			
Mobile Homes	0	33	58
Single-Family Detached	0	163	300
Low Density	0	40	80
Multi-Family, Low-Rise	0	53	114
Multi-Family, High-Rise	0	28	62
Total	0	317	614
Commercial			
Office Buildings	0	145	351
Retail Establishments	0	124	301
Schools	0	73	160
Hospitals	0	49	97
Other	0	113	226
Total	0	504	1,135

SOURCE: Arthur D. Little, Inc. Estimates

TABLE V-4

ANNUAL ENERGY SAVINGS POSSIBLE BY ADOPTION OF ASHRAE 90 BY ALL STATES

(Trillions of Btu)

	1975	1980	1985	1990
	0	33	58	83
etached	0	163	300	447
	0	40	80	118
ow-Rise	0	53	114	165
igh-Rise	0	28	62	87
	0	317	614	900
gs	0	145	351	619
hments	0	124	301	528
	0	73	160	259
	0	49	97	150
	0	113	226	433
	0	504	1,135	1,989

Little, Inc. Estimates

saved by 1980. This would increase to approximately 1.8 quads by 1985, and to 2.9 quads by 1990.

The comparable data continued in Tables V-1, V-3, and V-4 are summarized in Figures V-8 and V-9. Figures V-8 shows that the potential energy which could be saved by the year 1990 due to the adoption of ASHRAE 90 is about 27% of the energy consumed by those buildings constructed after 1975. A more significant fact is that even with complete adoption (and enforcement) of ASHRAE 90 by all states, annual energy demand in the construction sector will continue to increase over the period 1975 to 1990, although at a lesser rate (1.4% per year versus 2.3% per year).

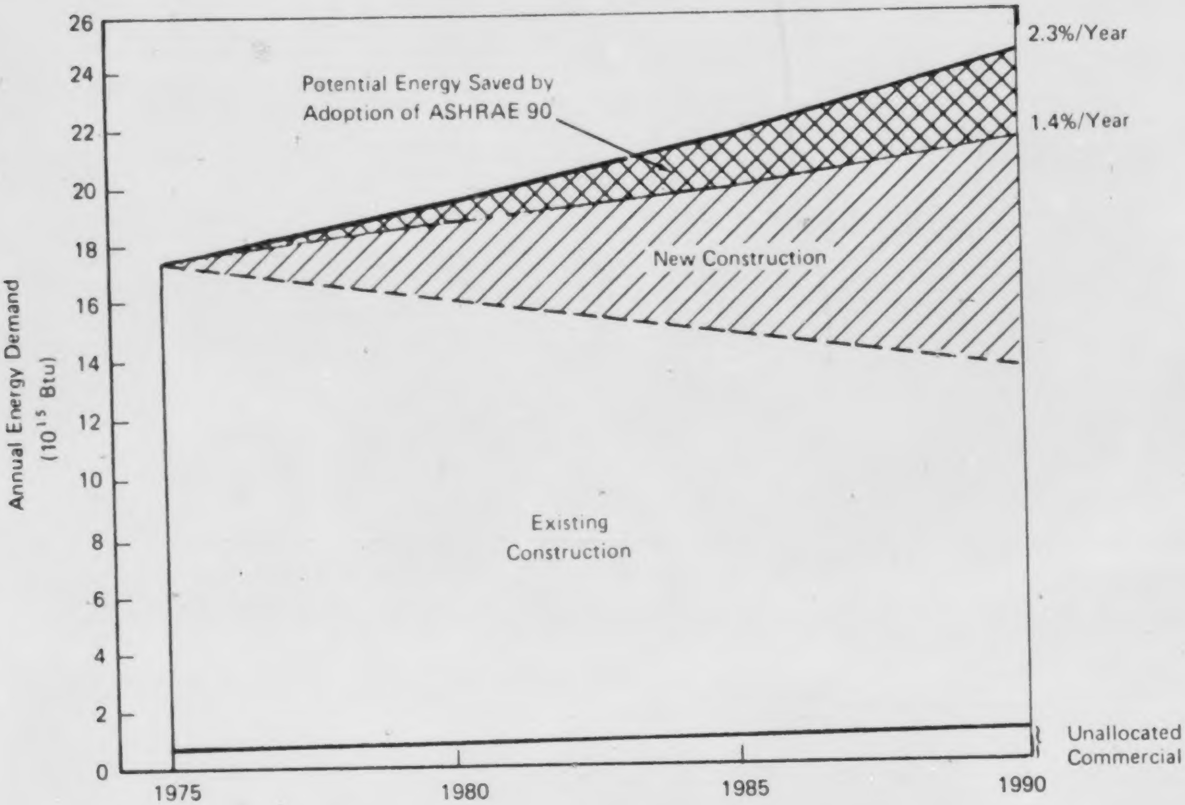
These estimates are in agreement with the previous CEQ/FEA study in which it was estimated that the maximum potential reduction for new and existing buildings was 6.2 quads in 1990, resulting in an average annual growth rate of 0.8%.

Figure V-9 separates the impact of the standard between the residential and commercial sectors. Consistent with the findings in Chapter III, the reduction in annual energy usage is considerably greater in the commercial sector. In relation to the earlier estimates on energy consumption by end use, this indicates that while the residential sector accounts for more consumption, most of the savings under ASHRAE 90 would be realized in commercial construction. If the standard were more effective in residential construction, the total potential annual energy savings would be considerably greater.

Perhaps the most appropriate way in which to evaluate potential savings is by percent. Table V-5 shows that the potential energy saved by adoption of ASHRAE 90 by all states equals 4.2%, 8.1%, and 11.9% of total annual energy consumption for the years 1980, 1985, and 1990, respectively.

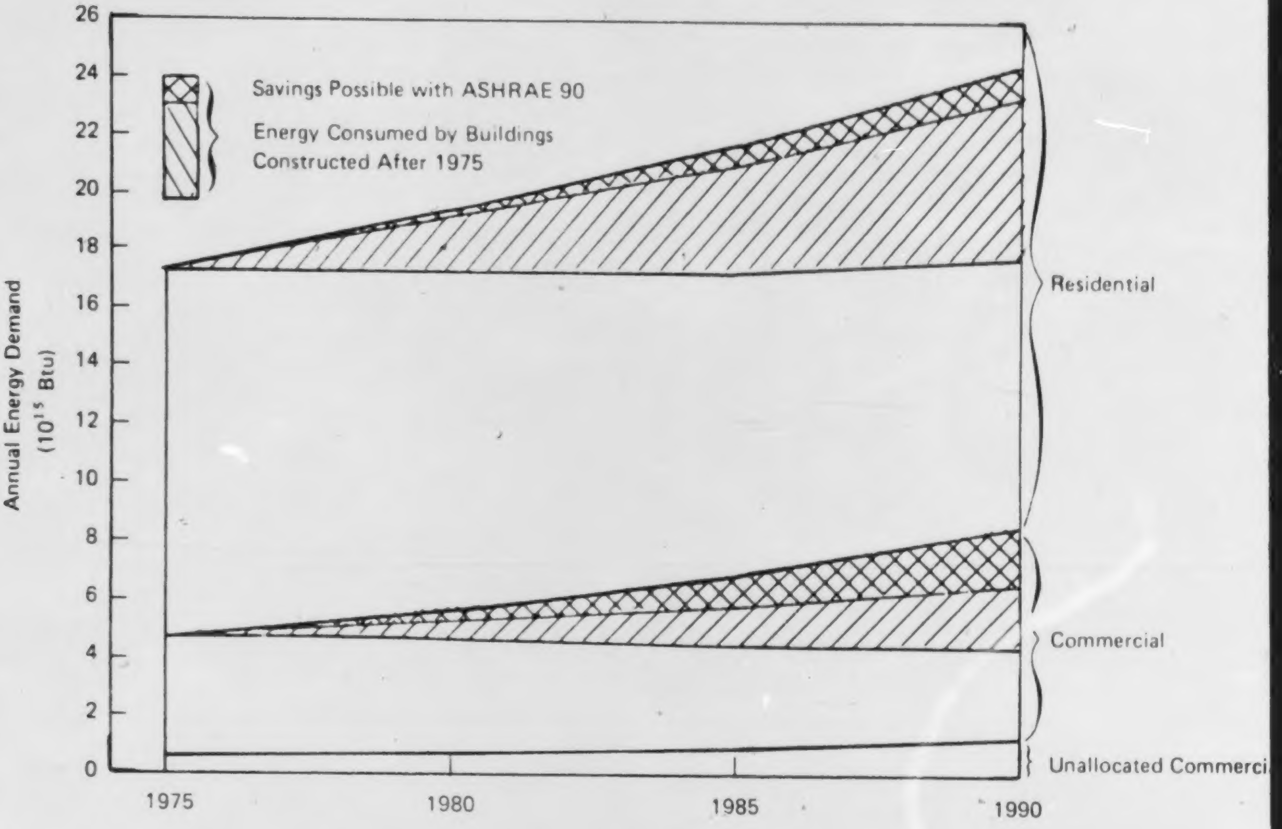
Table V-6 and Figure V-10 shows the potential energy saved by year and by Census region. The North Central region accounts for the largest energy demand although the amount of annual demand in 1990 which is attributable to buildings built after 1975 is greater in both the South and West. The potential energy saved by adoption of ASHRAE 90 will be greater in the North Central region when expressed as a percent of total energy consumed (13.1%). The major cause for this is the region's higher per unit space heating load, an area where ASHRAE 90 is very effective.

Finally, some mention should be made of the impact on annual energy consumption due to the adoption of ASHRAE 90 by the various groupings of states which have taken some action in adopting energy conservation legislation. Figure V-11 shows that the annual growth rate in energy consumption could be reduced only if all states adopt ASHRAE 90. However, if only those states which presently have mandatory laws granting authority to state regulatory agencies adopt the standard, the annual average growth rate would be reduced to 1.9%. If those states which have voluntary laws also adopt ASHRAE 90, this would be reduced to 1.8%, and if those states that have either laws or bills pending during this legislative year were to adopt the standard, annual average growth rate would be reduced to 1.6%.



Source: Arthur D. Little, Inc., estimates.

FIGURE V–8 POTENTIAL IMPACT OF ASHRAE 90 ON ANNUAL ENERGY CONSUMPTION, 1975–1990



*Energy Measured at Building Boundary.

Source: Arthur D. Little, Inc., estimates

FIGURE V–9 POTENTIAL IMPACT OF ASHRAE 90 ON ANNUAL ENERGY CONSUMPTION,* RESIDENTIAL AND COMMERCIAL DEMAND, 1975–1990

TABLE V-5

ANNUAL SAVINGS POSSIBLE BY ADOPTION OF ASHRAE 90

(Percent)

	1980	1985	1990
Total Annual Energy Consumed in Construction (Trillions of BTU)	19,465 (100%)	21,612 (100%)	24,189 (100%)
Annual Energy Consumed By Buildings Built After 1975			
Residential	11.9	20.5	26.7
Commercial	5.5	11.1	17.2
TOTAL	17.4	31.6	43.9
Potential Energy Saved By Adoption of ASHRAE 90			
Residential	1.6	2.8	3.7
Commercial	2.6	5.3	8.2
Total	4.2	8.1	11.9

SOURCE: Arthur D. Little, Inc., Estimates

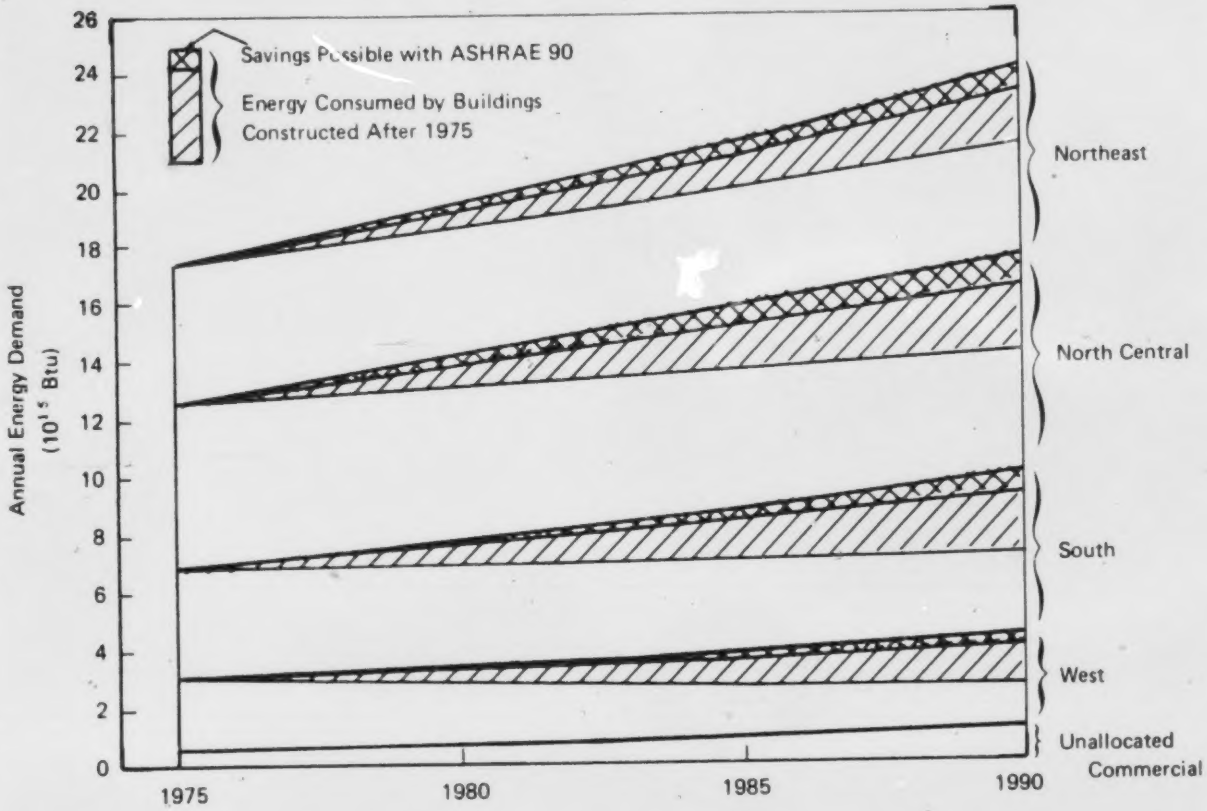
TABLE V-6

ANNUAL SAVINGS POSSIBLE BY ADOPTION OF ASHRAE 90, BY REGION

(Percent)

	1980	1985	1990
Total Annual Energy Consumed in Construction (Trillions of BTU)			
Northeast	5,329	5,831	6,457
North Central	6,258	6,858	7,598
South	4,412	5,008	5,685
West	2,718	3,010	3,351
Annual Energy Consumed by Buildings Built After 1975			
Northeast	14.8	27.7	39.6
North Central	17.7	32.1	45.3
South	21.1	37.7	51.5
West	20.8	37.1	50.9
Potential Energy Saved By Adoption of ASHRAE 90			
Northeast	4.2	8.4	12.6
North Central	4.6	8.8	13.1
South	4.4	8.2	12.0
West	4.2	8.0	11.8

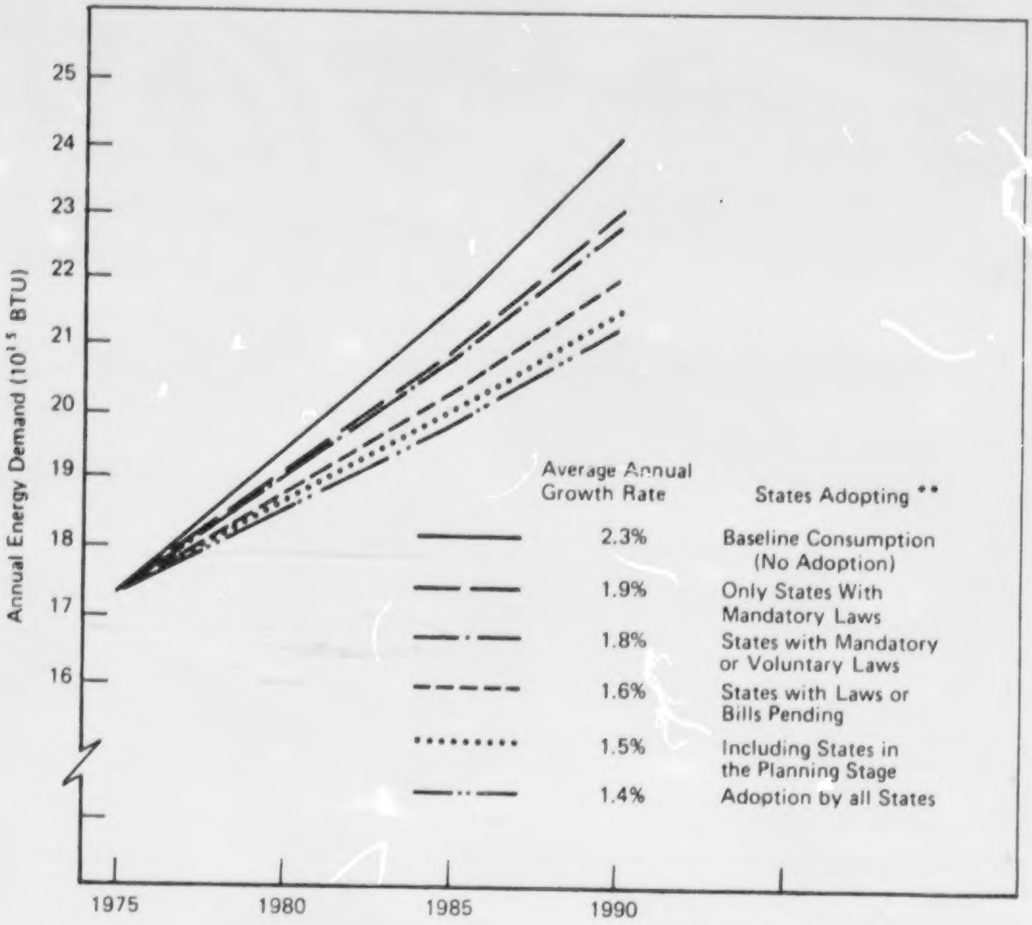
SOURCE: Arthur D. Little, Inc. Estimates



*Energy Measured at Building Boundary.

Source: Arthur D. Little, Inc., estimates.

FIGURE V–10 MAXIMUM POTENTIAL SAVINGS* POSSIBLE WITH ASHRAE 90 BY REGION, 1975–1990



* Energy Measured at Building Boundary

** As of June, 1975

Source: Arthur D. Little, Inc. Estimates

FIGURE V–11 COMPARATIVE IMPACT ON ANNUAL ENERGY CONSUMPTION * DUE TO ADOPTION OF ASHRAE 90 BY VARIOUS STATES

In conclusion, we believe that ASHRAE 90 could be an effective document if adopted only by those states presently having either existing mandatory or voluntary statutes or with bills pending.

CHAPTER VI

APPLICABILITY OF ASHRAE 90 WITHIN THE U.S. CONSTRUCTION INDUSTRY

A. INTRODUCTION

Section 2 (Scope) of ASHRAE 90 states that the proposed standard is applicable to:

> New buildings that provide facilities or shelter for public assembly, education, business, mercantile, institutional, warehouse and residential occupancies which are primarily used for human occupancy...

The document further states that it is intended for mobile homes and manufactured buildings, but not for structures whose peak design rate of energy usage is less than one watt per square foot (3.4 Btu/hr/sq.ft.).

Given this definition, ASHRAE 90 is applicable to only a certain segment of the U.S. construction industry. Considerable construction takes place which is not new construction intended for human occupancy, and therefore is not susceptible to ASHRAE 90.

After first defining the industry, the purpose of this chapter is to evaluate the overall applicability of the standard in terms of the amount of annual expenditures which could potentially be affected if ASHRAE 90 were to be adopted by all code authorities.

B. THE U.S. CONSTRUCTION INDUSTRY

For the purposes of this project, the U.S. construction industry shall be defined to consist of three major categories: new construction, repair and remodeling, and mobile homes.

Regarding new construction, there are four subcategories, not all of which would be covered by ASHRAE 90 although future guidelines on energy conservation will probably be applicable to virtually all domestic construction. The four subcategories are as follows:

1) *Residential* - Includes detached single-family residences, low-density housing (2 to 4 units) and multi-family units, both low-rise and high-rise.

2) *Nonhousekeeping Residential* - Includes building quarters such as hotels (other than apartment hotels), motels, dormitories, nursing homes, etc.

3) *Nonresidential Buildings* - Includes industrial, mercantile, commercial, institutional, educational, hospital, and religious buildings and other nonresidential structures such as buildings used as motion picture studios or theaters or in providing amusement and recreation services. Also included are radio and television stations, bus and airline terminal buildings, animal hospitals, fire stations, police stations, and correctional facilities.

4) *Nonbuilding Facilities* - Includes nonresidential auxiliary facilities which are intended to serve commercial buildings under construction. These are primarily civil projects such as parking lots, streets, sidewalks, sewer and water facilities, etc.

Construction activity within the last subcategory is reported in a series of smaller classifications. One such classification is entitled "public utilities," where the construction reported includes not only the type of civil construction peculiar to the operation of the utility (i.e., power plant), but also includes certain types of nonresidential buildings built by utilities for their own use, such as office buildings. Such buildings also come under the jurisdiction of local and/or state building codes, and as such, ASHRAE 90 would apply if adopted by that particular regulatory authority. However, it was assumed that virtually all of the construction reported under "nonbuilding facilities" is not occupancy-oriented, and thus, the category as a whole would not be affected by ASHRAE 90.

Construction expenditures for the second major category, repair and remodeling, may be classified into three subcategories:

1) *Maintenance and Repairs* - Includes work to existing structures or service facilities (e.g., repapering, repainting, reroofing, street and highway patching). This type of activity accounts for approximately 30% of total repair and remodeling expenditures.

2) *Additions and Alterations* - Includes such items as additions of a wing or one or more floors to an existing building, conversion of space to other uses, or the installation of service facilities to an existing building. Additions and alterations account for approximately 50% of total repair and remodeling expenditures.

3) *Major Replacements* - Replacements are distinguished from additions and alterations in that major replacements are not innovations. This type of activity accounts for the remaining 20% of annual repair and remodeling expenditures.

While data on the amount and value of both residential and nonresidential new construction are available through a variety of government and industry sources, accurate data on repair and remodeling expenditures is scarce. The only source of such information in the residential sector is published by the Census Bureau,[1] and includes maintenance and repairs, additions and alterations, and major replacements. Residential repair and remodeling expenditures historically have correlated with growth in personal income and have ranged between 40% to 60% of the value of new residential construction put-in-place.

For nonresidential buildings and nonbuilding construction, repair and remodeling expenditures must be estimated because there is no published data available. To estimate these expenditures, additions and alterations must first be separated from new construction (they are reported as one figure). Based on available residential data, it was assumed that additions and alterations comprise 10% of new construction and 50% of the total repair and remodeling market. Thus, new construction value in each nonresidential building and nonbuilding category was decreased by 10% to derive additions and alterations, and then doubled to derive total repairs and remodeling expenditures.

Data on the final category, mobile homes, is reported by a number of sources, and includes conventional coaches 8' to 16' in length, expansion coaches, and double-wides. Motorized campers and other recreational vehicles have been omitted.

Given the above diversity, the most appropriate way in which to define the size of the U.S. construction industry is in terms of the value of construction put-in-place. This is a measure of the installed or erected value at the site during a given period, generally one calendar year. For an individual project, this includes the cost of materials installed, the cost of labor performed, a proportionate share of the cost of construction equipment used, the cost of architectural and engineering work, the contractor's profit, the project owner's overhead costs, and miscellaneous costs chargeable to the project on the owner's books.[2] In the case of mobile homes, the value put-in-place includes the cost of tie down and utility connections.

The total value in place for a given period is the sum of the value put-in-place on all projects underway during this period, regardless of when work on each individual project was started or when payment was made to the contractors. As will be discussed in the next section, the value of construction put-in-place in 1976 was estimated to be $168.5 billion, and includes new construction, repair and remodeling, and mobile homes.

---

[1] Construction Reports Series C50, "Residential Alterations and Repairs."

[2] The basic data for value of new construction comes from the Department of Commerce/Bureau of the Census in Construction Reports Series C-30, "Value of New Construction Put-In-Place." Adjustments were made to the data in order to fit construction sector definitional requirements and to completely separate major additions and alterations from new nonresidential building and nonbuilding construction.

C. OUTLOOK FOR NEW CONSTRUCTION, 1976

Tables VI-1 and VI-2 show the forecasted construction volume and value of new construction put-in-place for 1976, respectively. It was estimated that new residential construction will be on the order of 1.5 million units with a resurgence in new commercial construction not anticipated until late-1976 at the earliest.

1. Residential Construction

ADL does not foresee the traditional role of a strong recovery in residential construction leading the economy out of its present recession. Major reasons for this position are as follows:

- In past recessions, reduced corporate loan demand for inventory financing and capital spending usually released funds for home mortgages. However, the rapid build-up in savings institutions balances over the past year did not lead to significant declines in new home mortgage rates. After reaching a high of 9.27% in December, 1974, new home mortgage rates in June, 1975, averaged 8.96% and are presently rising.
- The alternative use of these initial savings inflows by the banks were primarily to retire existing short-term debt, and fears of another major downturn have made many mortgage lenders reluctant to step up their loan volume. These fears may well be justified as the latest rates for three-month Treasury bills have increased and large Eastern savings banks are now experiencing savings outflows.
- Finally, inflation in residential construction is still running above 9%, reducing the ability of more and more people to afford home ownership. This is reflected in the improved apartment vacancy rates and the doubling-up trend in many areas across the country. Even the National Association of Homebuilders have lowered their estimate of 1975 private housing starts to 1.1 million, down 17% from 1974.

In summary, although housing starts surged 14% in July to an adjusted annual rate of 1.24 million, a prolonged recovery is not likely to occur for the above reasons and a continuation in high unemployment rates. ADL estimates residential construction to show a real growth of 28% in 1976; however, new housing starts are anticipated to reach a moderate level of only 1.5 million units.

TABLE VI-1

FORECASTED NEW CONSTRUCTION, 1976

	Northeast	North Central	South	W
RESIDENTIAL (1000's of units)	199	365	627	
Single-family[1]	147	279	456	
Low-rise Multi-family	31	75	132	
High-rise Multi-family	21	11	39	
NONHOUSEKEEPING RESIDENTIAL (MM sq.ft.)	4.2	6.2	9.1	
NONRESIDENTIAL (MM sq.ft.)				
Office and Banks	20.5	35.9	63.6	
Retail Establishments	23.4	47.1	62.7	
Educational	30.4	42.6	62.7	
Hospitals and Health	14.9	23.7	25.8	
Industrial	41.0	68.1	76.7	
Other Nonresidential	--	--	--	

---

[1] Includes low density, two to four units.

SOURCE: Arthur D. Little, Inc., estimates.

TABLE VI-1

FORECASTED NEW CONSTRUCTION, 1976

	Northeast	North Central	South	West	Total
nits)	199	365	627	309	1500
	147	279	456	218	1100
	31	75	132	74	312
	21	11	39	17	88
IAL (MM sq.ft.)	4.2	6.2	9.1	6.8	26.3
t.)					
	20.5	35.9	63.6	40.0	160.0
	23.4	47.1	62.7	36.8	170.0
	30.4	42.6	62.7	34.3	170.0
	14.9	23.7	25.8	10.6	75.0
	41.0	68.1	76.7	44.2	230.0
	--	--	--	--	345.0

o to four units.

, Inc., estimates.

TABLE VI-2

VALUE OF NEW CONSTRUCTION PUT-IN-PLACE

(billions of constant 1967 dollars)

	1974	1975[1]	1976	Annual Cha 1975
RESIDENTIAL	$23.3	$17.5	$22.5	-24.9
Single-Family Detached	14.9	12.8	16.9	-14.0
Low Density	1.4	1.0	1.2	-28.6
Multi-Family, Low-Rise	5.6	3.2	3.8	-42.9
Multi-Family, High Rise	1.4	0.5	0.6	-64.3
Total	46.6	35.0	45.0	
COMMERCIAL	16.3	13.4	12.6	-17.8
Office Buildings	3.4	2.7	2.5	-20.0
Retail Establishments	5.4	3.8	3.6	-29.6
Schools	0.38	0.3	0.3	-21.1
Hospitals and Institutional	1.9	1.7	1.6	-10.5
Industrial	4.1	4.0	3.8	-2.4
Other Nonresidential	1.1	0.9	0.8	-18.2
Total	32.58	26.8	25.2	

---

[1] Estimated based on annual volume through May, 1975.

SOURCES: U.S. Department of Commerce; Arthur D. Little, Inc., estimates.

TABLE VI-2

VALUE OF NEW CONSTRUCTION PUT-IN-PLACE

(billions of constant 1967 dollars)

				Annual Change (Percent)	
	1974	1975[1]	1976	1975	1976
	$23.3	$17.5	$22.5	-24.9	28.6
etached	14.9	12.8	16.9	-14.0	32.0
	1.4	1.0	1.2	-28.6	20.0
ow-Rise	5.6	3.2	3.8	-42.9	18.9
igh Rise	1.4	0.5	0.6	-64.3	20.0
	46.6	35.0	45.0		
	16.3	13.4	12.6	-17.8	-6.0
s	3.4	2.7	2.5	-20.0	-7.4
hments	5.4	3.8	3.6	-29.6	-5.3
	0.38	0.3	0.3	-21.1	0.0
Institutional	1.9	1.7	1.6	-10.5	-5.9
	4.1	4.0	3.8	-2.4	-5.0
ential	1.1	0.9	0.8	-18.2	-11.1
	32.58	26.8	25.2		

---

ed on annual volume through May, 1975.

Department of Commerce; Arthur D. Little, Inc., estimates.

2. Nonresidential Construction

Through the first seven months of 1975, nonresidential construction contracts totaled $18.8 billion, down 3.6% from the previous year. Over the same period, dollar value of contracts was off 12% from the previous year indicating that the decline is still continuing. In constant dollar terms, outlays were off 8.5% in the first half of 1975, and are expected to decline 12.6% for the entire year.

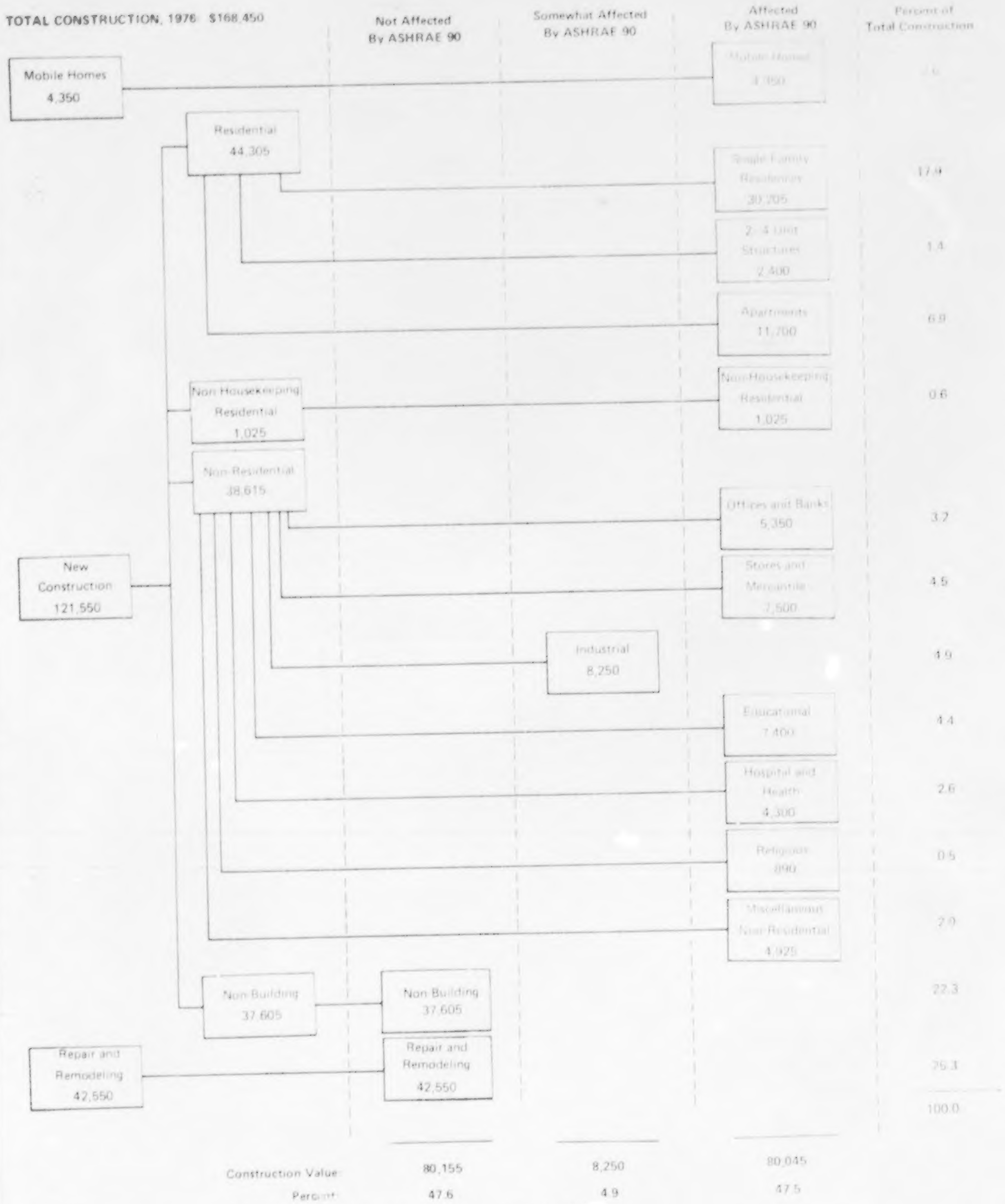
Because of large idle capacity, the nonresidential construction market may remain depressed well into 1976. McGraw-Hill reported that manufacturing operating rate in July, 1975, was 69% of capacity, down substantially from 83.5% in July, 1974. Furthermore, declining corporate profits (down 23.4% in the first half of 1975) are reducing the availability of internal funds for expansion.

The fact that nonresidential construction has not fallen off as quickly in the first half of 1975, as was expected for the entire year, reflects the cyclical lag in construction completion. Much of the nonresidential construction's strength in the past year emanated from the completion of projects commenced when prospects for the economy were brighter. Again, this supports the position that a resurgence in nonresidential construction will probably not occur until late 1976 or early 1977.

D. SEGMENT OF THE CONSTRUCTION INDUSTRY AFFECTED BY ASHRAE 90

Figure VI-1 summarizes the various sections of the construction industry that would be affected by ASHRAE in 1976, the first year the document would be in effect. Of the total $168.5 billion, $121.6 billion (72%) is for new construction, $4.4 billion (3%) for mobile homes, and $42.6 billion (25%) is for repair and remodeling. Assuming adoption of the standard by all states, $80.0 billion, or slightly less than half of total construction value would be directly affected by ASHRAE 90 with an additional $8.3 billion (5%) being only somewhat affected. Thus, a total of approximately 52% of domestic construction could be affected by ASHRAE 90 in some manner. Expenditures for nonbuilding construction and repair and remodeling represent approximately 48% of total value put-in-place, and although they may eventually be regulated by other energy conservation guidelines, these expenditures are not affected by ASHRAE 90.

Another consideration is what proportion of the total affected volume of new construction ($88.3 billion) is accounted for by those states which either have passed, or are in the process of passing, legislation granting statewide authority to regulate energy usage in buildings. As discussed previously, not all states are presently in a position to incorporate ASHRAE 90, or some similar standard, into their building codes. Other states have developed their own conservation regulations. Table VI-3 shows the value of affected residential and nonresidential construction within each of the six groupings of states discussed in Chapter II.


TOTAL CONSTRUCTION, 1976 $168,450
Not Affected By ASHRAE 90
Somewhat Affected By ASHRAE 90
Affected By ASHRAE 90
Percent of Total Construction
Mobile Homes 4,350
Mobile Homes 4,350
2.6
Residential 44,305
Single Family Residences 30,205
17.9
2–4 Unit Structures 2,400
1.4
Apartments 11,700
6.9
Non Housekeeping Residential 1,025
Non-Housekeeping Residential 1,025
0.6
Non-Residential 38,615
Offices and Banks 5,350
3.2
New Construction 121,550
Stores and Mercantile 7,500
4.5
Industrial 8,250
4.9
Educational 7,400
4.4
Hospital and Health 4,300
2.6
Religious 890
0.5
Miscellaneous Non-Residential 4,925
2.9
Non-Building 37,605
Non-Building 37,605
22.3
Repair and Remodeling 42,550
Repair and Remodeling 42,550
25.3
100.0
Construction Value: 80,155 8,250 80,045
Percent: 47.6 4.9 47.5

Source: Department of Commerce Statistics, ASHRAE 90–75; Arthur D. Little, Inc., estimates

FIGURE VI–1 APPLICABILITY OF ASHRAE 90–75 WITHIN THE U.S. CONSTRUCTION INDUSTRY; VALUE OF CONSTRUCTION PUT-IN-PLACE, 1976 (MILLIONS OF CURRENT DOLLARS)

TABLE VI-3

VALUE OF CONSTRUCTION AFFECTED BY ASHRAE 90-75, 1976

(millions of current dollars)

Grouping*	Affected			Somewhat Affected
	Residential	Nonresidential	Total	
States with Mandatory Laws	18,680	12,284	30,964	3,420
States with Voluntary Laws	2,209	1,380	3,589	250
States with Bills Pending	12,713	9,273	21,986	2,121
States in the Study or Planning Stages	6,070	4,979	11,049	1,308
States whose bills have been killed by the Legislature	697	510	1,207	132
States in which No Action Is Taking Place	3,936	2,964	6,900	1,019
TOTAL	44,305	31,390	75,695	8,250
Mobile Homes			4,350	---
Nonbuilding			---	---
Repair & Remodeling			---	N.A.
TOTAL			80,045	8,250
			(47.6%)	(4.9%)

---

*Groupings of states based on existing and pending legislation as of June, 1975.

SOURCE: Arthur D. Little, Inc., estimates.

TABLE VI-3

VALUE OF CONSTRUCTION AFFECTED BY ASHRAE 90-75, 1976

(millions of current dollars)

	Affected			Somewhat	
	Residential	Nonresidential	Total	Affected	Not Affected
aws	18,680	12,284	30,964	3,420	
aws	2,209	1,380	3,589	250	
ng	12,713	9,273	21,986	2,121	
Planning	6,070	4,979	11,049	1,308	
been killed	697	510	1,207	132	
on Is	3,936	2,964	6,900	1,019	
	44,305	31,390	75,695	8,250	
			4,350	---	
			---	---	37,605
			---	N.A.	42,550
			80,045	8,250	80,155
			(47.6%)	(4.9%)	(47.5%)

sed on existing and pending legislation as of June, 1975.

le, Inc., estimates.

In general, the majority of construction value is accounted for by those states which either have mandatory or voluntary laws or which have bills pending. States which are only in planning stages, which had bills in legislation but were killed, or which are taking no action, represent only a minor share of construction activity. The latter point is emphasized in Table VI-4, which shows the cumulative percent of affected construction for each grouping of states.

Twenty-nine states have taken, or are taking, positive action and account for 75% of the value of construction in 1976 which could be affected by ASHRAE 90. The remaining 21 states which have taken little action account for only 25% of affected construction value. From this it is concluded that if ASHRAE 90 is adopted as a voluntary consensus standard only by those states presently in a position to do so, its coverage--along with those states which have developed their own energy conservation regulations--would be significant.

Finally, Table VI-5 shows that of the 45% of total construction (excluding mobile homes) which could be directly affected by ASHRAE 90, 34% is accounted for by states which have taken or are taking affirmative action. Based upon the recent NBS survey which indicated that many such states are actively looking to adopt ASHRAE 90, it can be concluded that the standard's acceptance could be rapid and its applicability would be widespread.

TABLE VI-4

CONSTRUCTION VALUE OF STATES ADOPTING BUILDING ENERGY CONSERVATION LEGISLA

AS OF JUNE 1975

Grouping	Number of States	Value of Affected Construction, 1976 (millions of dollars)	Percen
States with Mandatory Laws	18	30,964	41
States with Voluntary Laws	2	3,589	5
States with Bills Pending	9	21,986	29
States in the Study or Planning Stages	6	11,049	14
States whose bills had been killed by the Legislature	3	1,207	2
States in which No Action Is Taking Place	12	6,900	9
TOTAL	50	75,695	100

SOURCE: Arthur D. Little, Inc., estimates.

TABLE VI-4

ON VALUE OF STATES ADOPTING BUILDING ENERGY CONSERVATION LEGISLATION

AS OF JUNE 1975

	Number of States	Value of Affected Construction, 1976 (millions of dollars)	Percent	Cumulative Percentage
tory Laws	18	30,964	41	41
tary Laws	2	3,589	5	46
Pending	9	21,986	29	75
dy or Planning	6	11,049	14	89
s had been killed e	3	1,207	2	91
Action Is	12	6,900	9	100
TOTAL	50	75,695	100	

Little, Inc., estimates.

TABLE VI-5

PERCENT OF TOTAL CONSTRUCTION (1976) AFFECTED BY ASHRAE 90-75 IN CONJUNCTION WITH THOSE STATES ADOPTING BUILDING ENERGY CONSERVATION LEGISLATION AS OF JUNE, 1975

		Percent
TOTAL CONSTRUCTION, 1976:		100
Less Those Sections Not Affected, Or Only Somewhat Affected, by ASHRAE 90-75		
- Repair and Remodeling	25	
- Nonbuilding New Construction	22	
- Industrial Buildings	5	52
Construction Affected by ASHRAE 90-75		48
Less Mobile Homes		3
In-Place Construction Affected by ASHRAE 90-75:		45
By Status of State Legislation:		
• States with Mandatory Laws	19	
• States with Voluntary Laws	2	
• States with Bills Pending	13	
• States in the Study or Planning Stages	6	
• States whose bills had been killed by the Legislature	1	
• States in which No Action Is Taking Place	4	
	45	

SOURCE: Arthur D. Little, Inc., estimates.

CHAPTER VII

ECONOMIC IMPACT OF ASHRAE 90 ON SELECTED INDUSTRIES

A. INTRODUCTION

Following an initial screening, ten subindustries within the construction sector were identified which would be economically affected--either positively or negatively--by the adoption of ASHRAE 90. The subindustries can be divided into three general product categories: building materials suppliers, building equipment suppliers, and HVA/C systems suppliers.

This chapter discusses the impact of ASHRAE 90 on each industry sector after first presenting a definition of the products involved and a profile of the market. As in previous chapters, emphasis was placed upon determining the maximum impact of the standard.

B. IMPACT ON INSULATION SUPPLIERS

1. Product Definition

All materials used in the construction of the "shell" of a residential or commercial building are "insulation" to the extent that they serve as a barrier to the heat loss (or gain) of the interior of the structure. For the purposes of this study, insulation materials shall be limited to those materials whose primary function is to impede heat transfer by providing thermal barriers.

Insulation materials are subclassified into structural and industrial, pipe and equipment. Structural insulation may further be categorized by density (batts and blown-in wall insulation versus rigid boards), both of which are affected by ASHRAE 90. Similarly, only that "industrial" insulation which relates to mechanical and plumbing systems in residential and commercial buildings (duct insulation and pipe insulation) was considered. Insulation sold to original equipment manufacturers (OEM) such as appliance manufacturers, and that used to fabricate products whose primary function is not insulating values (e.g., ceiling panels) was not considered.

The dominant insulation material used in residential and nonresidential construction is fiberglass. Fiberglass represented 70% of the shipments of insulation materials reported by the Census of Manufacturers in 1972. Of the materials used in the above defined categories, fiberglass represents nearly 85% of shipments. Other materials used include mineral wool, and plastic foams (principally styrene and urethanes). The majority of mineral wool--once the predominant building insulation material--now goes into the production of ceiling tiles and industrial uses. Foam insulation materials are relatively new products, and have not been able to materially penetrate the market position of fiberglass.

2. Industry Characterization

The insulation industry is highly concentrated. Presently there are only three manufacturers of fiberglass insulation in the United States. Of the three companies, only one derives the majority of its revenues from the sale of fiberglass insulation. The other two firms are diversified, primarily in the building industry, and fiberglass insulation accounts for less than 25% of their annual revenues.

Foam products are manufactured by a wider range of producers. Producers of urethane products are primarily chemical companies which have integrated forward into foam from a position in raw material manufacturing. In addition, a few nonchemical companies have entered the business, resulting in approximately 20 companies which are participants in this market. None has a dominant share.

Extruded polystyrene foams are the exclusive province of one company which holds the basic patents on the process. Expanded polystyrene foam, or "beadboard," is produced by a process which requires little capital investment, and as a result, the industry is comprised of a number of small firms scattered throughout the country. The industry is, however, in transition, and a number of large well-capitalized firms have entered, or are planning to enter the market.

3. Market Analysis

Table VII-1 lists the sales history of fiberglass as reported by the Department of Commerce. It indicates that from 1965 to 1974, the shipments of wool glass fiber doubled, from 1,046 million pounds to nearly 2 billion pounds. This represents an annual average growth rate of approximately 7.5% per year. Structural building insulation has grown at a more rapid rate than industrial usages, or at about 12% per year.

ADL estimates the current dollar volume of the total industry is approximately $860 million per year, with fiberglass representing 70% of total industry shipments. Table VII-2 details sales by product category for the last year for which comprehensive data are available (1973). Approximately 60% of all insulation sales go to the product categories which are covered by ASHRAE 90.

Table VII-3 details the breakdown of sales by product category and market. In 1973, approximately one-half of the value of all insulation sales (in those categories which concern ASHRAE 90) went to new residential construction, with 11% going to the retrofit market and 39% going to commercial construction.

By 1974, these relationships shifted slightly due to the sharp decline in residential construction and the increased demands for retrofit resulting from the "energy crisis." It is estimated that new construction accounted for only 40% of total sales, with retrofit increasing to 22% and commercial remaining constant at 39%.

TABLE VII-1

U.S. SHIPMENTS AND VALUE OF FIBERGLASS, 1964-1971*

Insulation Use	1965 MM lb	1965 $ MM	1965 ¢/lb	1966 MM lb	1966 $ MM	1966 ¢/lb	1967 MM lb	1967 $ MM	1967 ¢/lb	1968 MM lb	1968 $ MM
Structural Building	438	93	21.1	484	105	22.6	484	109	22.5	557	133
Industrial, Pipe & Equipment	608	158	26.0	608	173	28.5	554	170	30.7	567	179
Total	1,046	251	24.0	1,072	278	25.9	1,038	279	26.9	1,124	312

	1969 MM lb	1969 $ MM	1969 ¢/lb	1970 MM lb	1970 $ MM	1970 ¢/lb	1971 MM lb	1971 $ MM	1971 ¢/lb	1972 MM lb	1972 $ MM
Structural Building	627	158	25.2	644.8	165.6	25.7	890	218	24.5	1,055	268
Industrial, Pipe & Equipment	675	198	29.3	541.5	190.6	35.2	627	207	33.0	684	219
Total	1,302	356	27.3	1,186.3	355.8	30.0	1,517	425	28.0	1,738	487

	1973 MM lb	1973 $ MM	1973 ¢/lb	1974 MM lb	1974 $ MM	1974 ¢/lb
Structural Building	1,180	310	26.3	1,162	340	29.3
Industrial & Equipment	725	249	34.3	739	258	34.9
Pipe				43**	52**	1.21
Total	1,904	559	29.4	1,944	650	33.4

---

*Values are average manufacturers' net selling prices, f.o.b. plant, after discounts and allowances, freight and excise taxes.

**1974 was the first year in which pipe was listed as a separate end-use distinct from Industrial an

SOURCE: Department of Commerce, "Current Industrial Reports"

TABLE VII-1

. SHIPMENTS AND VALUE OF FIBERGLASS, 1964-1971*

965		1966			1967			1968		
MM	¢/lb	MM lb	$ MM	¢/lb	MM lb	$ MM	¢/lb	MM lb	$ MM	¢/lb
93	21.1	484	105	22.6	484	109	22.5	557	133	23.9
158	26.0	608	173	28.5	554	170	30.7	567	179	31.6
251	24.0	1,072	278	25.9	1,038	279	26.9	1,124	312	27.8

69		1970			1971			1972		
MM	¢/lb	MM lb	$ MM	¢/lb	MM lb	$ MM	¢/lb	MM lb	$ MM	¢/lb
58	25.2	644.8	165.6	25.7	890	218	24.5	1,055	268	25.4
98	29.3	541.5	190.6	35.2	627	207	33.0	684	219	32.0
56	27.3	1,186.3	355.8	30.0	1,517	425	28.0	1,738	487	28.0

973		1974		
MM	¢/lb	MM lb	$ MM	¢/lb
310	26.3	1,162	340	29.3
249	34.3	739 43**	258 52**	34.9 1.21
559	29.4	1,944	650	33.4

rs' net selling prices, f.o.b. plant, after discounts and allowances, and excluding

ch pipe was listed as a separate end-use distinct from Industrial and Equipment.

, "Current Industrial Reports"

TABLE VII-2

SALES OF INSULATION MATERIALS BY PRODUCT CLASS, 1973

(Millions of Dollars)

RESIDENTIAL AND COMMERCIAL INSULATION PRODUCTS

	Fiberglass	Mineral Wool	Foams	Other	Total
Structural	310	--	20	10	340
Rigid Board	50	--	50	--	100
Pipe & Duct Insulation	50	10	--	--	60
Subtotal	410	10	70	10	500

INDUSTRIAL AND OTHER

	Fiberglass	Mineral Wool	Foams	Other	Total
Pipe & Duct Insulation	70	30	--	50	150
OEM	55	--	--	--	55
Ceiling Panels	25	130	--	--	155
Subtotal	150	160	--	50	360
TOTAL	560	170	70	60	860

TABLE VII-3

SALES OF INSULATION PRODUCTS BY MARKET, 1973

(Millions of Dollars)

Product Type	New Residential Construction	Residential Remodel/ Retrofit	Commercial	Total
Structural	220	55	65	340
Rigid Board	5	--	95	100
Pipe & Duct Insulation	25	--	35	60
	250	55	195	500

Table VII-4 further breaks down the new residential construction market by building type. Single-family homes account for 54% of this market, multi-family structures account for 30%, and mobile homes account for 16%. Single-family structures use approximately twice as much structural insulation per unit as do multi-family structures. This is based on two factors: single-family units are larger (1,600 square feet versus 1,000 square feet) and single-family units have a greater proportion of wall and roof area to floor area than multi-family units. Virtually all the rigid board and pipe and duct insulation is used in multi-family structures, while the $55 million of remodel and retrofit sales typically have gone entirely to the single-family market.

Over the past two years sales of insulation products have been affected by two contrary factors. Rising fuel prices plus increased consciousness of energy saving techniques have led to an increased usage per unit of consruction for insulation materials. However, this increase has been largely counteracted by the severe declines in construction activity experienced since mid-1973. The net effect of these factors was a leveling off of sales in 1974. Industry projections indicate a 6% increase in volume in 1975.

Approximately 70% of structural fiberglass is in batt form, 15% is blown-in-wall, and 15% is sold directly to mobile home manufacturers in roll form. Of the shipments in roll or blanket form, currently 75% is in 3 1/2" thickness (R-11) and 25% is 6" thickness (R-19). As late as 1972, one-third of all such shipments were 2 1/2" thickness (R-7), and only 11% were R-19. The apparent change in product mix can be attributed directly to the effects of the "energy crisis." It appears that R-11 in the walls and R-19 in the ceilings (essentially the requirements under ASHRAE 90) are becoming standard industry practice.

4. Product Trends

Neither mineral wool nor foam products have been able to successfully penetrate fiberglass' share of the structural insulation market. While foam insulation has desirable technical properties, it costs significantly more than fiberglass, and has the additional drawback of being a flammable material. Current FOB plant costs for 2" extruded polystyrene are $12 per square (100 square feet), and for 1" board urethane, they are $16 per square. In contrast, a 3 1/2" fiberglass batt costs $7 per square. In that the R value of the batt is 11 versus 8 for the other two materials, it is not difficult to see why fiberglass has maintained its share of the market.

Where rigid insulation products are required (such as in roof board), foam products can effectively compete with fiberglass on a cost/value basis. In fact, these products are most often sold purely on the basis of cost per U-value, with the different materials being freely substitutable. Their usage, however, is limited by code restrictions in some cases. Urethane in particular cannot be used in many areas due to its flammability. However, urethanes can compete effectively in the market for industrial pipe insulation, with fiberglass and calcium silicate products.

TABLE VII-4

MARKETS FOR INSULATION MATERIALS IN NEW RESIDENTIAL CONSTRUCTION, 1973

(Millions of Dollars)

	Single-Family	Multi-Family	Mobile Home	Total
Structural	130	50	40	220
Rigid Board	---	5	--	5
Pipe and Duct	5	20	--	25
Total	135	75	40	250

It is likely that fiberglass will maintain its dominant share in the insulation industry over the foreseeable future. The primary reason for this is its superior performance and lower price in the largest segment of the industry: structural insulation for residential and commercial structures. Other materials will continue to be used in the areas where their product characteristics warrant such usage but the major areas for their growth (industrial pipe insulation, cold storage, cryogenics) will be outside the auspices of ASHRAE 90.

5. Methods of Distribution

The methods of marketing and distribution for insulation products differ by product category and end market. The majority of structural batt and blown-in-wall insulation for new construction is sold through wholesale distributors to contractors and developers. Developers will solicit bids from insulation manufacturers, and generally specify only product type. Insulation for these uses is considered a commodity product, and little "brand" loyalty is observed.

A small amount of such insulation (estimated to be less than 5%) may be sold directly from the producer to the developer, in the case of the large national and regional developers. This method is more prevalent in the cases of insulation sold for the use of mobile home manufacturers.

6. Quantitative Impact of ASHRAE 90

ASHRAE 90 places great emphasis on increasing the levels of thermal insulation in buildings. The increased insulation requirements lie in three areas: structural insulation for residential and commercial buildings, perimeter and roof insulation for commercial buildings; and loose-fill insulation for certain classes of commercial structures. Based upon ADL's estimates of the increased insulation requirements and the anticipated levels of construction activity, the increased demand for insulation materials due to the adoption of ASHRAE 90 is shown in Table VII-5.

The estimated $45 million increase in requirements for structural insulation represents a 13% increase in total product sales and a 16% increase in those product sales going to new construction (the portion of the market affected by the standard). Of total fiberglass production, these new requirements represent 8% of sales, and it is unlikely that other products will be utilized to meet these requirements.

Regarding perimeter and roof insulation, the estimated $128 million increase represents a 55% increase in product sales to this market where virtually all of the current market is new construction. Of the total production of all materials which can be used interchangeably for roof or perimeter insulation (plastic foams, fiberglass board, perlite, soft board) the new demand represents a 28% increase in product sales.

Finally, the $6 million increase in demand for loose-fill insulation represents a 113% increase in product sales to the construction market.

TABLE VII-5

INCREASED INSULATION MARKETS DUE TO ASHRAE 90, 1976

(Millions of Dollars)

Type	Sector	Northeast	North Central	South
Structural	Residential and Commercial	12.3	23.6	6.2
Perimeter and Roof Insulation	Commercial	8.4	24.4	58.8
Loose-Fill	Commercial	0.8	1.7	2.2
Total				

SOURCE: Arthur D. Little, Inc., estimates.

TABLE VII-5

SED INSULATION MARKETS DUE TO ASHRAE 90, 1976

(Millions of Dollars)

	Northeast	North Central	South	West	Total
nd Commercial	12.3	23.6	6.2	3.2	45.3
	8.4	24.4	58.8	36.4	128.0
	0.8	1.7	2.2	1.3	6.0
					179.3

, estimates.

However, of the total production of the materials which could be used for this application, it represents only a 19% increase in total sales.

7. Qualitative Impact of ASHRAE 90

Due to the depressed state of the domestic construction industry, demand for all building materials has dropped from the levels anticipated by manufacturers. Fiberglass is no exception. A review of those plants currently producing fiberglass in the United States shows that there are several plants which currently have either curtailed or delayed production. While fiberglass sales have held up better than other industries (due to the effects of the energy crisis of 1973-74), these sales have not met the demand anticipated by producers. As a result, the industry is currently operating at a reduced level of capacity, and the increases in demand required by ASHRAE 90 should be able to be met adequately by current production facilities.

Two points should be noted. First, the demand for increased insulation due to the needs for energy conservation have long been anticipated by fiberglass producers, and the current overcapacity in the industry represents to a good degree the investments made in anticipation of this demand. Secondly, the requirements for increased insulation are overstated to the degree that they represent increases over the standards of construction which existed prior to the oil embargo of October, 1973 and the fact that they represent maximum impacts due to a strict interpretation of the standard.

Since 1973, the standards for thermal insulation required by building occupants, and subsequently supplied by builders, has increased dramatically. The previously discussed shift in product mix in insulation sales toward the higher thicknesses represents a per unit increase of approximately 15% in pounds of structural insulation sold for 1974 over 1973. These figures indicate that in fact the requirements of ASHRAE 90 may be already met by the industry, and the actual effect of the standard on the industry will be minimal.

In contrast to the structural insulation, the $128 million increase in requirements for roof and perimeter insulation represents the largest increase (in terms of markets and production) necessitated by ASHRAE 90. This is due largely to the fact that pre-embargo buildings used such insulation only to a minor degree, and assuming that such will be required for virtually all commercial buildings, the effects on the current market seem large.

However, as discussed previously, there are in fact a number of products which can be used to provide these types of insulation. If these products are interchangeable, and are priced on thermal resistance basis, then a major impact might result if one assumed that all of the increased requirements were to be supplied by one material (such as polystyrene). The impact when viewed in light of the wide range of products which can be offered, should not be significant.

It should also be noted that when discussing the increase in sales for total markets discussed previously in this section, only those products which went to the construction market were included. In fact, if the total production of the raw materials with which these products are made is included (plastic resins, fiberglass wool, softboard, perlite), the impact is small. (For example, the polystyrene resin industry is a $1.0 billion industry, only a small fraction of which goes to construction-related uses.) Here as in the structural insulation industry, one can assume that some of the effect of the ASHRAE 90 standards has already been felt in the wake of the recent energy crisis.

Finally, it was assumed that retail establishments utilizing concrete block construction will meet the ASHRAE 90 requirements by filling their cavities with loose insulation. Based on this assumption, it was estimated that there will be requirements for $6 million more of these materials. Loose-fill insulation can be either exfoliated vermiculite or fiberglass. Currently, the majority of the sales for this application are of vermiculite and they amount to approximately $5 million per year. If all of the increased requirements were to be met from this material, an impact might result. However, total sales of vermiculite are ten times the amount which goes for insulation purposes. In addition, ADL anticipates that much of any increased requirements will be met by fiberglass, which as discussed previously, has ample excess capacity. As a result, it is not anticipated that a major impact on either industry will result due to the standard.

C. IMPACT ON SIDING MATERIALS SUPPLIERS

1. Product Definition

There is little difficulty in defining those product categories which are incorporated in the generic class of "siding materials." They include brick, wood products (including natural wood, plywood, and hardboard), concrete (precast, cast-in-place, and block), metal (steel and aluminum), stucco, and other (plastic, asbestos, etc.). From a data gathering standpoint, however, it is difficult to determine the actual usage of these materials for siding purposes. For each of the above materials siding represents only a fraction of the total product sales. In some cases, such as brick, this fraction is substantial. In others, however, such as wood products and plastic, it is small compared to total industry production.

2. Industry Characterization

The market for siding materials is highly dispersed both in terms of the number of products which are offered, and in the number of companies in each product category which offer the material. There is little horizontal integration in the industry, as siding represents mainly vertical integration within a materials lines, and the suppliers are identified primarily by the material rather than by the product.

The most concentrated of the product categories is wood products. Even here, however, there are a wide range of companies in the market. The least concentrated are brick and concrete, which are primarily local or regional operations. All product segments are currently operating under very low capacity utilization, due to the depressed state of the construction industry.

3. Market Analysis

No hard data exists to say definitively what the sales of each material to the residential and commercial siding markets might be. It is more difficult to analyze changes in these relationships over time.

The estimates detailed in Table VII-6 are based on first estimating the usage rates of all siding materials by building class through the derivation of a wall-to-floor ratio for each building type. These usage rates are multiplied by the square footage of construction in each product class to derive an estimate of total siding sales on a regional basis for each building type. Against these, estimated market penetrations were applied on a regional basis for each material to arrive at product sales by material and building type. By aggregating these, and applying current product prices, the estimates of total market shown in the table were arrived at.

Brick is the dominant siding material in all regions, but it is most prevalent in the South. Its market share has been declining over the past decade at the expense of other products (particularly wood and concrete).

Wood products have a strong market share in all regions for all building types, but their strongest markets are in the Northeast and West, and for multi-family buildings. A particularly fast growing segment of the residential market has been hardboard siding, which can simulate natural wood textures, at a significantly lower cost.

Stucco is used almost exclusively in the West, and primarily for residential construction.

Metal (primarily steel) has made significant market penetrations in commercial structures. Alternatively, aluminum siding (as well as plastics) have made little impact on the new residential market. Both products are used primarily in the remodeling market.

Over time, the sales of siding materials will closely follow expenditures for residential and commercial construction. No dramatic shifts in the market shares of individual products are anticpated although the trends which have been exhibited over the past few years, as described above, should continue.

The $850 million sales of siding materials to new residential and commercial construction represent approximately 85% of sales of these materials for siding materials, the balance being for the remodeling market. The percentage of product going to the after-market is less for

TABLE VII-6

ESTIMATED SALES OF SIDING MATERIALS, 1973

(Millions of Dollars)

Sector	Brick	Wood	Concrete	Metal	Stucco	Other	Total
Residential	350	150	90	40	50	30	710
Commercial	80	10	10	10	10	20	140
Total	430	160	100	50	60	50	850

SOURCE: Arthur D. Little, Inc., estimates siding than is typical for commodity building materials in general. This is explained by two factors: 1) many of the products used (e.g., brick, concrete) last indefinitely, and therefore, there are few requirements for repair or replacement over the useful lives of buildings; and 2) those materials which do deteriorate, primarily wood, can be repaired through retreatment of the surface, such as staining or repainting, rather than through replacement.

There is severe competition among the manufacturers of siding materials for business in the new residential and commercial construction markets. Unlike most of the materials and products discussed in this study, siding materials are important aesthetic elements in buildings. As a result, product selection is based on appearance, as well as performance and price. The success of brick siding in this market, despite its higher price relative to most other materials, attests to the willingness of consumers to pay premiums for products which appeal to them visually.

The perceptions of consumers as to which siding material is most desirable varies significantly by region. In some regions there are strong ingrained product preferences which make penetrations of new siding materials very difficult. Manufacturers thus tend to concentrate on maintaining and expanding market shares in those markets in which they have a presence, rather than trying to crack markets where other materials are dominant.

Most successful penetrations of new products in new markets have been in the commercial sector, where external appearance is often less important than in the residential market. In the prestige sectors of the commercial market, however, strong product preferences persist, and material such as steel and hardboard have had less success in gaining footholds. While regional preferences have declined somewhat as the population becomes more mobile, these preferences should remain strong in most areas.

4. Product Trends

There has been a product trend in recent years away from the traditional materials such as brick, and toward materials such as metal and concrete. Wood, which is a traditional market entrant, has expanded its market share through the introduction of new products, primarily hardboard. As indicated above, these trends will continue, but will be tempered by the inertia of strong local preferences for individual materials.

5. Methods of Distribution

As in most construction markets, the marketing and distribution systems for siding materials varies by markets served. In the residential market, most siding materials are sold through wholesale buildings materials dealers. The contractors will solicit bids from the various dealers in the material he has chosen to use (due to market preferences) for future delivery. Within the product category, he will bargain over price. He will not, however, typically change his preconception as to the material to be used on this basis.

In the commercial market, particularly in the prestige end of the market, siding manufacturers may take a more active role in the selling process. They will call on architects to attempt to have their materials used in lieu of others. This form of selling, however, is less prevalent than for other types of building materials.

6. Economic Impact of ASHRAE 90

Siding materials will be affected by ASHRAE 90 in two ways. First, as an integral part of the building envelope, their thermal insulation properties contribute directly to the effectiveness of the building in retaining energy. Second, they are affected indirectly by standards relating to fenestration--the less glass allowed, the more siding materials need be used. We determine that the effect of these two concurrent factors has been to increase the demand for siding materials in most cases. Such increases, however, have proved to be minor.

ADL estimates that the net effect of ASHRAE 90 will be to increase sales of siding materials by approximately $12 million annually. This increase will vary from no impact in some regions for some building types, to large increases required in two markets--office buildings in the South and West. In this latter case, it was initially assumed that the current standards of construction will not be able to meet ASHRAE 90 and methods which utilize less glass and more siding must be employed. This is a relatively small market segment, however, and the effects of this shift on the total sales of siding materials will be minor.

The effect of the standards are detailed on Table VII-7. It can be seen that the impact is minor, in total, by market, and for each material. The impact will be to increase by 1.5%, total siding sales to the new construction markets. They vary by material from 1.0% for wood products to 3.4% for "other," which is primarily cinder block.

When compared to total siding sales in new construction, the total impact drops to 1.5%. When measured against the total product sales of companies involved in the siding industry, the impact is a fraction of a percent of total production. Given this level of impact, and the current underutilized capacity available in the industry, it appears that no measurable impact on siding materials suppliers will result from the application of ASHRAE 90.

D. IMPACT ON WINDOW AND WINDOW GLASS SUPPLIERS

1. Product Definition

The sectors covered in this industry profile include products used for fenestration in new residential and nonresidential buildings and consist of flat glass, wood window units, sashes, and frames, and steel, aluminum and other metal window units, sashes and frames. This analysis

TABLE VII-7

INCREASES IN SIDING MATERIALS DUE TO ASHRAE 90, 1976

(Millions of Dollars)

Sector	Brick	Wood	Concrete	Stucco	Metal	Other	Total
Residential	1.8	0.9	0.2	0.2	0.2	0.1	3.4
Commercial	4.5	0.6	1.0	0.9	0.6	1.4	9.0
Total	6.3	1.5	1.2	1.1	0.8	1.5	12.4

SOURCE: Arthur D. Little, Inc., estimates.

does not include nonglass products used for window lites; tempered glass, frequently used in glass doors but infrequently in fenestration; or window units and frames that are site-fabricated and glazed. The latter products are believed to be a small and declining proportion of total fenestration in the United States.

Three different types of flat glass exists: sheet, plate and float. The principal distinction between these types is technological, i.e., the manufacturing processes are quite distinct although markets and applications frequently overlap for each.

Sheet glass can be either "thin," weighing between four ounces and sixteen ounces per square foot; "window," weighing between sixteen ounces and twenty-eight ounces; or "heavy," weighing over twenty-eight ounces per square foot. Window glass is a common glazing material for residential construction and is available single-strength (18-19 ounces) or double (24-26 ounces). Single strength glass is about 3/32" and double strength about 1/8". Both heavy sheet and float glass are used in commercial construction and certain residential applications, such as tempered patio doors, and are typically purchased in thicknesses of 5/32" to 7/32". Plate and float glass are used in store display windows and curtain walls.

Wood windows, sashes and frames are either standard or custom fabrication millwork items almost exclusively using softwood lumber. This lumber is received in a semi-processed form from the sawmills and is then cut to appropriate profiles, nailed and glued by the millwork manufacturers in fabricating the window products. In contrast, materials for metal windows (principally aluminum, a declining amount of roll-formed steel and very small quantities of bronze) are semifabricated in an extruded form by the basic metal producers and then assembled into window products.

2. Industry Characterization

The production of sheet, plate, and float glass in the United States is highly concentrated and involves only seven companies. It is estimated that over 85% of the U.S. output of sheet glass is produced by the leading four manufacturers. In addition to these four, two others produce float glass; however, three of the top four account for all plate glass manufacturing. A seventh company produces only sheet glass.

The two largest suppliers to the construction industry are large, multi-product firms producing a wide range of flat glass products, including tempered, as well as other industrial products. The third major company produces float and tempered glass primarily for its own consumption in the manufacture of vehicles, but also for sale to the trade. A number of smaller independent companies are also included in the glass industry, mainly in the lamination and tempering of glass; however, only three are of any size.

The 10 companies and 31 plants in the flat glass industry shipped $937 million of product in 1972. The level of shipments has increased from 1967 to 1972 at an annual average rate of approximately 9%. There are presently 11 sheet, 3 plate and 15 float glass plants in the U.S. today, down considerably from those operating a decade ago.

Table VII-8 shows the domestic shipments of flat glass over the past five years. Domestic shipments of sheet glass have changed only slightly during this period, when allowance is made for the considerably poorer residential construction market in 1974. However, sheet glass has lost market penetration to other forms of glass and plate and float glass almost maintained the same level of shipments in 1974, despite the poorer demand situation. In a typical year, about 70% of sheet glass consumption is in windows and other building-related applications, while the ratio is about 35% for float and plate glass.

Sheet glass represents a gradually reducing proportion of total flat glass value of shipments, while float glass was about $350 million in 1974. Apparent average prices per pound remained steady in 1974, as compared to 1973, reflecting the poorer demand situation. In fact, many producers temporarily closed down facilities (representing considerable fixed assets--up to $35 million for a single float glass line) or postponed expansion plans due to poor capacity utilization.

It should be pointed out that imports of sheet glass are a significant factor in the total consumption. These imports increased during the 1960's and reached a level in 1968 that caused sufficient alarm in the glass industry for it to seek some form of action by the U.S. Tariff Commission. In that year, sheet glass imports accounted for 32% of U.S. consumption; they declined in absolute terms in 1969 and 1970 but then increased in 1971 and 1972. As a percentage of U.S. consumption, they still represent about 30%. U.S. imports of plate and float glass also increased in the late 1960's and now represent about 5% of domestic consumption.

The consumption of glass in new nonresidential construction has been estimated at 130 million square feet annually; an additional 95 million square feet is apparently consumed in remodeling and replacement of nonresidential construction.

In summary, estimates of 1974 consumption of flat glass in buildings (including fenestration, but also including sky lights, doors, storm windows, etc.) are as follows:

Residential	- Prime	275
	- Storm	340
Nonresidential	- New	130
	- Replacement	95
		840 million square feet

TABLE VII-8

SHIPMENTS OF FLAT GLASS, 1970 - 1974

	Sheet Glass Including Colored, Total		Plate, Float, and Rolled and Wire Glass	
	MM Sq. Ft.	$ MM	MM Sq. Ft.	$ MM
1970	1,069	131.5	698	253.2
1971	1,188	150.3	943	314.3
1972	1,196	157.2	1,191	393.3
1973	1,126	152.2	1,404	433.0
1974	905	131.6	1,378	407.4

SOURCE: U.S. Department of Commerce/Bureau of the Census, *Current Industrial Reports* (MQ-32A)

Turning to window fabricators, no reliable estimates are available on the number of companies involved in the production of metal windows. However, product shipments including interplant transfers are reported by the Census as follows:

	$ Million
Residential Steel	11.4
Residential Aluminum	344.5
Nonresidential Steel	11.2
Nonresidential Aluminum	84.6
Other-All Metals	59.9
Total	$511.6

Although a number of larger companies are involved in the manufacture of metal windows, the industry can generally be characterized as containing small, local or regional fabricators.

Shipments of wood windows, sashes and frames increased from approximately $210 million in 1967 to $391 million in 1972, an average annual rate of growth of 13.5%. (It should be noted that this growth rate strongly reflects the very different market prices prevalent for softwood lumber in 1967 and 1972.) As with metal windows, the manufacturers of millwork products are typically small, regional or local companies.

Regarding the sales of window units, a number of different sources were examined in attempting to derive an estimate of the number of windows of all materials used in new residential and nonresidential construction. The most reliable and consistent data are apparently those available from industry sources. Table VII-9 derived the number of windows used in new residential construction for the period 1965-1974. Table VII-10 shows, for the same years, the types of materials used in these windows. Examination of these two tables will underscore the following points:

- The total number of windows consumed fluctuates greatly with the level of residential construction and no real growth pattern emerges. In fact, there has been a slight decline in the average number of windows used per residential unit, both for one- and two-family and apartment construction.

- Aluminum windows, except in 1967 and 1968, have held over 80% of those units used in apartment construction and generally more than 50% of those in one- and two-family units. Steel windows have almost as large a market share of apartment construction as do the wood windows but steel has been losing penetration of total new residential construction and now represents 3%.

TABLE VII-9

ESTIMATED NUMBER OF WINDOWS USED IN NEW RESIDENTIAL CONSTRUCTION,[1] 1965-1974

Year	1 and 2 Family		Apartments		All Residential Construction, Total Windows[2] (Millions)
	Windows per Unit	Total Windows (Millions)	Windows per Unit	Total Windows (Millions)	
1965	17.3	17.7	7.8	3.8	21.5
1966	17.0	13.9	7.4	2.8	16.7
1967	16.9	15.1	7.0	3.0	18.1
1968	16.9	16.1	6.7	4.0	20.1
1969	16.6	14.3	6.4	4.1	18.4
1970	16.1	13.9	6.1	3.7	17.6
1971	15.9	19.4	6.1	5.3	24.7
1972	15.9	22.0	6.0	6.0	28.0
1973	16.1	19.1	6.0	5.2	24.3
1974[3]	16.1	14.9	6.1	2.6	17.5
Change 1974 versus 1973 (percent)		-22%		-50%	-28%

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[1] All materials, including aluminum, wood, steel, and other materials.

[2] Includes basement and above-ground windows.

[3] Preliminary.

SOURCE: Architectural Aluminum Manufacturers' Association estimates, based on various sources.

TABLE VII- 10

ESTIMATED INDUSTRY USE OF ALUMINUM, WOOD, AND STEEL WINDOWS IN NEW RESIDENTIAL CONSTRUCTION

(Millions)

	1 and 2 Family				Apartments				Total Resid		
Year	Alum.	Wood	Steel[1]	Total	Alum.	Wood	Steel[1]	Total	Alum.	Wood	S
1965	8.0	8.8	0.9	17.7	3.1	0.6	0.1	3.8	11.1	9.4	
1966	6.3	6.9	0.7	13.9	2.3	0.4	0.1	2.8	8.6	7.3	
1967	6.9	7.7	0.5	15.1	2.3	0.5	0.2	3.0	9.2	8.2	
1968	8.5	7.4	0.2	16.1	3.0	0.6	0.4	4.0	11.5	8.0	
1969	7.2	7.0	0.1	14.3	3.5	0.3	0.3	4.1	10.7	7.3	
1970	7.1	6.5	0.3	13.9	3.0	0.4	0.3	3.7	10.1	6.9	
1971	10.1	8.9	0.4	19.4	4.3	0.6	0.4	5.3	14.4	9.5	
1972	11.9	9.7	0.4	22.0	4.9	0.7	0.4	6.0	16.8	10.4	
1973	9.8	8.9	0.4	19.1	4.2	0.6	0.4	5.2	14.1	9.5	
1974[2]	7.6	7.0	0.3	14.9	2.1	0.3	0.2	2.6	9.7	7.3	
% Change 1974 vs. 1973	-22%	-21%	-25%	-22%	-50%	-50%	-50%	-50%	-31%	-23%	

---

[1] Includes steel and other unidentified materials.

[2] Preliminary

SOURCE: Architectural Aluminum Manufacturers' Association estimates, based on various sou

TABLE VII- 10

LUMINUM, WOOD, AND STEEL WINDOWS IN NEW RESIDENTIAL CONSTRUCTION, 1965-1974

(Millions)

ily		Apartments				Total Residential			
l[1]	Total	Alum.	Wood	Steel[1]	Total	Alum.	Wood	Steel[1]	Total
9	17.7	3.1	0.6	0.1	3.8	11.1	9.4	1.0	21.5
7	13.9	2.3	0.4	0.1	2.8	8.6	7.3	0.8	16.7
5	15.1	2.3	0.5	0.2	3.0	9.2	8.2	0.7	18.1
2	16.1	3.0	0.6	0.4	4.0	11.5	8.0	0.6	20.1
1	14.3	3.5	0.3	0.3	4.1	10.7	7.3	0.4	18.4
3	13.9	3.0	0.4	0.3	3.7	10.1	6.9	0.6	17.6
4	19.4	4.3	0.6	0.4	5.3	14.4	9.5	0.8	24.7
4	22.0	4.9	0.7	0.4	6.0	16.8	10.4	0.8	28.0
4	19.1	4.2	0.6	0.4	5.2	14.1	9.5	0.7	24.3
3	14.9	2.1	0.3	0.2	2.6	9.7	7.3	0.5	17.5
5%	-22%	-50%	-50%	-50%	-50%	-31%	-23%	-29%	-28%

unidentified materials.

minum Manufacturers' Association estimates, based on various sources.

- Aluminum share of new residential construction increased steadily during the 1960's and into the 1970's but peaked in 1972 and has declined since then. This decline might possibly be due to a similar decline in the level of housing starts in the western region of the U.S., where aluminum windows are relatively more popular.

Precise data on the regional distribution of new residential windows by type of material is not available but it is evident that wood windows have a greater popularity in the Northeast and North Central parts of the nation, while aluminum windows are particularly strong in the South and West.

Storm window shipments amounted to an estimated 30.3 million units in 1974, increasing from 24.3 million in 1970. Each of these years has shown a growth in shipments, emphasizing the fact that storm window sales are largely related to existing building stock rather than new construction. Almost all of the storm windows are aluminum units, with wood units holding a steady 1.6 million unit shipments level throughout the 1970's.

Estimates based on data from industry sources suggest that 23.8 million prime window units were installed in 1974--18.8 million in new residential construction and the remainder as a replacement units (Table VII-11). In addition, 34.1 million storm windows were installed in spite of the fact that 1974 was a significantly bad year for new residential construction.

Estimates of the number of component windows used in nonresidential construction (as opposed to custom fabricated window walls and curtain walls) are difficult to make. According to industry estimates, aluminum windows in new nonresidential construction have increased from 3 million units in 1970 to 4.1 million units in 1974; the value of shipments has nearly doubled from $110.7 million to $218.9 million over the same period. In addition to these shipments for new construction, 0.8 million units ($51.8 million) was also shipped for replacement applications in 1974. In contrast, steel windows for nonresidential construction are relatively insignificant, at 266,000 units in 1972, valued at $11.2 million.

3. Product Trends

Significant product trends are occurring that will change both the design of building fenestration and the materials used within the next five to ten years. Some of the more important trends which affect energy conservation in buildings are as follows:

- Although there has been some attempt to promote the use of triple glazing, mostly by the addition of a storm window to double-glazed units, this trend is likely to be superseded by attempts to improve the performance of windows with better seals and the use of coated glass.

TABLE VII-11

ESTIMATED NUMBER OF WINDOWS INSTALLED IN RESIDENTIAL SECTOR, 1974

Type of Housing	Units Constructed 1974 (000's)	Windows/Unit	Windows Total (000's)
Prime Windows			
Detached Single Family	646.5	16	10,344
Attached Single Family	319.1	9	2,872
Multi-Family	386.8	6	2,321
Mobile Homes	329.3	10	3,293
Total New	1,681.7	(11.2)	18,830
Remodeling/Replacement	--	--	5,000
Total Prime			23,830
Storm Windows			
New			3,100
Remodeling/Replacement			31,000
			34,100

SOURCE: Arthur D. Little, Inc., estimates, based on industry data.

- The trend to smaller houses and residential units, stimulated by rapidly increasing costs of homebuilding and by some purchaser preferences, has also led to builders and architects increasing slightly the size of window areas as a promotional feature to counter the negative impressions created by reduced floor areas.

- On the other hand, it appears that little or no voluntary steps are being taken to reduce glass area or the number of windows as an energy conservation measure. The recently enacted energy bill in the State of California would seek to stipulate the type of glass used if the window areas in a house exceed 20% of the floor area--a distinct possibility in the open plan California-designed homes. Even if this measure is implemented successfully on the West Coast, it is likely to have little or no impact in other regions of the country as windows in most single-family homes represent about 15% of floor areas, and as little as 10-12% in apartments.

- Plastics are being used increasingly as a thermal barrier to prevent the conduction of heat between the inside and outside faces of the window structure. Such windows have been on the market for about five years but presently only represent about 5% of all residential windows. It is likely that they will gain in use and popularity over the next few years.

4. Methods of Distribution

Flat glass for new residential applications is normally (80-90%) shipped directly from the primary glass manufacturer to the millwork manufacturer or the metal window fabricator. These customers then complete the fabrication of glazed units before distributing them directly to the homebuilders or to lumberyards for remodeling and replacement sales. In a few cases (10-20%) where the window manufacturers do not represent major volumes of shipments, flat glass is purchased through glass distributors.

In contrast, distribution of glass to nonresidential applications, both new, remodeling or replacement, is rarely direct from the primary glass manufacturer and usually is through distributors. Major glass manufacturers either have a captive distribution network or have selected and prequalified strategically located independent distributors to handle their products. In the case of at least one major glass manufacturer, the company also plays an important role in the marketplace as curtain wall and window wall fabricators for nonresidential buildings; these fabricators would normally buy glass directly from the factories. After fabrication, window walls and curtain walls for nonresidential buildings are usually installed by the fabricators themselves, acting as contractors.

Wood windows are almost exclusively used in residential construction and then mostly in private homes. Millwork manufacturers purchase semi-processed softwood lumber direct from sawmills (which they may also own) and fabricate windows to custom and standard sizes. These units are almost always preglazed before sale to homebuilders and contractors.

While most aluminum windows are sold direct to the installer, aluminum, steel and other metal manufacturers sell shapes to window fabricators (often extruders) who, in turn, sell the preglazed, finished units to homebuilders and contractors for residential construction. In the case of nonresidential construction, these extrusions may be shipped to custom fabricators who work on a project-by-project basis to meet specific needs. Windows of standard dimensions, representing perhaps 70% of all nonresidential windows, are also sold by fabricators to independent contractors for installation and glazing by appropriate trades.

As with wood windows, metal windows are also used in remodeling construction. In those cases, retail channels play an important part in getting the projects to the remodeling contractor or the homeowner.

5. Economic Impact of ASHRAE 90

With respect to building fenestration, ASHRAE 90 would generally require reductions in the surface area of exposed glass, the amounts depending on the region and the type of building.

Table VII-12 shows, for each region, the amount of glass required in the conventional structure, and that which would be required if ASHRAE 90 requirements were to be met. For example, it is estimated that a single-family house located in the North Central region of the United States would have to reduce its average glass area from 0.154 square feet to 0.148 square feet per square foot of floor area. It will be noted that the amount of glass increases in all regions for the office building category. Interpretation of ASHRAE 90 results in the need for double glazing for this building type, thus resulting in an increased volume of glass although the exposed surface area will actually reduce. For example, the exposed surface area for an office building in the Northeast will reduce from about 0.128 square feet to 0.107 square feet per square foot of floor area, but the volume of glass will increase to 0.213 square feet.

Table VII-13 summarizes the percentage reduction in the exposed surface area for each of the 20 prototype buildings; Table VII-14 shows the net change in prime glass area resulting from these design assumptions. Here, it can be seen, for example, that while there will be no change in the prime glass area for multi-family, low-rise apartments constructed in the South, the glass area will reduce by 31 square feet for each housing unit in the North Central region. Based on the forecasts of construction activity in 1976 made in a previous chapter, these estimates of unit changes in net demand were translated into aggregate estimates for each building type and regions and for the U.S. as a whole (Table VII-15).

All building categories will experience a reduced demand on average (up to 7.8% in the multi-family, low-rise category) except for office buildings, where a significant increase (52%) could occur as a result of the requirement for insulated glass. Only in the North Central region is this increase in the office building sector insufficient to

TABLE VII- 12

IMPACT OF ASHRAE 90 ON GLASS AREA[1]

	Northeast		North Central		South		
	Conventional	ASHRAE 90	Conventional	ASHRAE 90	Conventional	ASHRAE 90	Conventi
Single-Family Residence	0.154	0.154	0.154	0.148	0.153	0.158	0.15
Low-Rise Apartment Building	0.144	0.123	0.144	0.113	0.144	0.144	0.14
Office Building	0.128	0.213	0.128	0.247	0.213	0.296	0.21
Retail Store	0.050	0.050	0.050	0.043	0.050	0.050	0.05
School	0.070	0.064	0.070	0.056	0.070	0.070	0.07

[1] Estimates account for both reduction in glass area and double glazing.

SOURCE: Arthur D. Little, Inc., estimates.

TABLE VII- 12

IMPACT OF ASHRAE 90 ON GLASS AREA[1]

st	North Central		South		West	
ASHRAE 90	Conventional	ASHRAE 90	Conventional	ASHRAE 90	Conventional	ASHRAE 90
0.154	0.154	0.148	0.153	0.158	0.151	0.149
0.123	0.144	0.113	0.144	0.144	0.144	0.135
0.213	0.128	0.247	0.213	0.296	0.213	0.307
0.050	0.050	0.043	0.050	0.050	0.050	0.050
0.064	0.070	0.056	0.070	0.070	0.070	0.070

both reduction in glass area and double glazing.

nc., estimates.

2

TABLE VII- 13

REDUCTION IN EXPOSED SURFACE AREA OF GLASS DUE TO ASHRAE 90

(Percent)

	Northeast	North Central	South	West	Total
Single-Family	----	4.1	----	1.3	1.0
Low-Rise Multi-Family	11.0	21.3	----	6.0	7.8
Office Building	16.7	3.3	30.6	28.2	22.0
Retail Store	----	13.3	----	----	4.7
School	7.5	20.0	----	----	6.7

SOURCE: Arthur D. Little, Inc., estimates.

TABLE VII- 14

NET CHANGE IN PRIME GLASS AREA DUE TO ASHRAE 90

(Sq. Ft. Glass/Unit)

Building Type	Unit	Northeast	North Central	Sc
Single-Family Residences	Start	----	-9.6	-
Low-Rise Apartment Building	Start	-16.0	-31.0	-
Office Building	Square Foot	+0.085	+0.119	+
Retail Store	Square Foot	----	-0.007	-
School	Square Foot	-0.006	-0.014	-

SOURCE: Arthur D. Little, Inc., estimates.

TABLE VII- 14

T CHANGE IN PRIME GLASS AREA DUE TO ASHRAE 90

(Sq. Ft. Glass/Unit)

	Unit	Northeast	North Central	South	West
	Start	----	-9.6	----	-3.4
	Start	-16.0	-31.0	----	-5.0
	Square Foot	+0.085	+0.119	+0.083	+0.094
	Square Foot	----	-0.007	----	----
	Square Foot	-0.006	-0.014	----	----

c., estimates.

TABLE VII- 15

IMPACT OF ASHRAE 90 ON DEMAND FOR PRIME GLASS, 1976

(Million Square Feet)

	Northeast			North Central			South			West			
	Conv.	ASHRAE 90	Change	Conv.	ASHRAE 90	Change	Conv.	ASHRAE 90	Change	Conv.	ASHRAE 90	Change	Conv.
Single Family	36.2	36.2	0	68.7	66.1	-2.6	120.7	120.7	0	56.1	55.4	-0.7	281.7
Low-Rise Apartments	4.5	4.0	-0.5	10.8	8.5	-2.3	19.0	19.0	0	10.7	10.0	-0.7	45.0
Office Building	2.6	4.4	+1.8	4.6	8.9	+4.3	13.5	18.8	+5.3	8.5	12.3	+3.8	29.2
Retail Store	1.2	1.2	0	2.4	2.0	-0.4	3.1	3.1	0	1.8	1.8	0	8.5
School	2.1	1.9	-0.2	3.0	2.4	-0.6	4.4	4.4	0	2.4	2.4	0	11.9
TOTAL	46.6	47.7	+1.1	89.5	87.9	-1.6	160.7	166.0	+5.3	79.5	81.9	+2.4	376.3
Weighted Total (MM lbs)*													707

* Assumes glass weight of 1.6 lbs./SF (single-family) to 4.35 lb./SF (office).

SOURCE: Arthur D. Little, Inc., estimates.

TABLE VII- 15

IMPACT OF ASHRAE 90 ON DEMAND FOR PRIME GLASS, 1976
(Million Square Feet)

	North Central			South			West			U.S. Total			
		ASHRAE			ASHRAE			ASHRAE			ASHRAE		
	Conv.	90	Change	Conv.	90	Change	Conv.	90	Change	Conv.	90	Change	%
	68.7	66.1	-2.6	120.7	120.7	0	56.1	55.4	-0.7	281.7	278.4	-3.3	-1.2
	10.8	8.5	-2.3	19.0	19.0	0	10.7	10.0	-0.7	45.0	41.5	-3.5	-7.8
	4.6	8.9	+4.3	13.5	18.8	+5.3	8.5	12.3	+3.8	29.2	44.4	+15.2	+52.1
	2.4	2.0	-0.4	3.1	3.1	0	1.8	1.8	0	8.5	8.1	-0.4	-4.7
	3.0	2.4	-0.6	4.4	4.4	0	2.4	2.4	0	11.9	11.1	-0.8	-6.7
	89.5	87.9	-1.6	160.7	166.0	+5.3	79.5	81.9	+2.4	376.3	383.5	+7.2	+1.9
	Weighted Total (MM lbs)*									707	759	+52	+7.4

gle-family) to 4.35 lb./SF (office).

compensate for the reductions in the other sectors so that the net change in that region is an estimated reduction of 1.6 million square feet (about 2%). (It should be noted that while the analysis calls for the use of insulated glass in office building construction, the designers may opt to use reflective glass to meet the requirements of ASHRAE 90.)

Comparable estimates were made for the remaining building categories for which prototypical designs were not carried out. As these categories are relatively small users of glass, aggregate totals of glass area did not change appreciably.

In summary, it is estimated that new building construction in 1976 will use about 422 million square feet of prime glass in meeting ASHRAE 90 standards, an increase of only 4.5 million square feet (1.1%). Assuming suitable glass weights for each building application, the volume of glass required will increase from 862 million pounds to 903 million pounds (plus 4.7%) as a direct result of ASHRAE 90. This increase is equivalent to about $6.9 million in value of shipments and represents approximately 0.6% of the $1,247 million of glass shipped in all product forms and for all uses by U.S. manufacturers in 1972.

The U.S. glass industry is presently operating at low capacity utilization rates, this incremental demand will help to improve these utilization rates. As the glass industry has relatively high capitalization-to-sales ratios, even such a modest increase will have a positive effect on the ability of the individual companies to cover fixed costs. In conclusion, ASHRAE 90 is expected to have a favorable impact on the flat glass industry.

The impact of reduction in exposed glass areas will not be as favorable on the window frames industry as it apparently will be on the flat glass industry. The net effect of ASHRAE 90 on the window frame industry will be a reduction of about 2.0% ($18.7 million) on domestic shipments ($903 million). This also represents a reduction of approximately 2.6% on the estimated size of the market in new construction ($720 million). All regions will experience these reductions in demand in some or all building categories; the greatest drop will again be in the North Central region. The greatest reduction in frame volume (minus 24.7%) is expected to occur in the office and bank category as that sector substitutes insulating glass of smaller (minus 22%) surface area to comply with ASHRAE 90. The smallest effect will occur in frames for single-family construction (minus 1.2%).

Finally, the U.S. window manufacturing industry is also presently operating at low-capacity utilization. Of the three principal types of window manufacturers--manufacturers of wood units, of aluminum units, and those custom fabricating for curtain wall construction--the most heavily impacted will be the curtainwall fabricators. Manufacturers of wood units primarily serving the residential markets will be least affected. However, the industry has a relatively low capitalization-to-sales ratio and thus a reduction in demand of about 2% should not have more than a modest negative impact on profitability.

E. IMPACT ON ELECTRIC LAMP MANUFACTURERS

1. Product Definition

Included in this section are electric lamps which are used for the illumination for buildings, with major emphasis on incandescent and fluorescent lamps. High intensity discharge lamps are discussed in a qualitative manner due to the absence of meaningful statistical information. Approximately 60% of lamp sales ($612 million out of total shipments of $1.08 billion in 1972) reported by the Department of Commerce are of interest to this study. Specifically excluded are shipments of photographic bulbs, sealed beam automotive lamps, miniature electric discharge lamps, and Christmas tree lamps.

2. Industry Characterization

The electric lamp industry in the United States is an oligopoly with three major manufacturers, one being dominant with close to a 50% share of market. There are minor manufacturers making specialty or long life lamps and a major European manufacturer is seeking to enter the U.S. market by acquiring a smaller domestic manufacturer.

There are two principal manufacturers of fluorescent lamps, each with an approximately equal market share, while the incandescent market share is dominated by the above one manufacturer. In the high intensity discharge lamp market, each of the major manufacturers produces a mercury vapor lamp but each of the other generic technologies is promoted primarily by an individual firm.

3. Market Analysis

Electric lamps used for the illumination of buildings may be categorized as three service types: incandescent, fluorescent and high intensity discharge (HID).

Incandescent lamps include the familiar residential screw-in type of light bulb providing traditional warm toned lighting for most residential applications. The most popular lamp in this category is the 100 watt bulb, followed closely by the 60 watt light bulb, which is becoming increasingly popular due to the "energy conservation ethic." Table VII-9 shows that shipments of large incandescent light bulbs were $400 million or 1.5 billion bulbs in 1974, representing an increase in number of lamps sold of 9.5% over 1967.

Fluorescent lighting has been growing at a slightly greater rate than incandescent as fluorescent is increasingly substituted for incandescent due to its higher illuminating efficiency. Historically, fluorescent lamps have suffered from a poor color spectra due to the nature of its discharge but recent improvements in the coating of the fluorescent tube have improved the color and enhanced the marketability of this product.

Table VII-16 also shows that total fluorescent lamp sales in 1974 were $246 million representing an increase of 21.7% over 1967's sales volume.

High intensity discharge (HID) lamps are of four generic types:

Type	Efficiency (lumens per watt)
Mercury vapor	50-60
Metal halogen	80-100
High pressure sodium	125-140
Low pressure sodium	180

All high intensity discharge lamps have the advantage of superior illuminating efficiency, but all also have the disadvantage of poor color rendition due to an incomplete spectrum. Each of the generic types has a major manufacturer promoting it, with the exception of the older mercury vapor lamps, which are manufactured and promoted by all major manufacturers.

Although statistics on HID lamp shipments are not available, a feeling for the rapid growth in demand for this type of lighting can be acquired from examining the increase in sales of HID fixtures. Between 1972 and 1974, the value of shipments of HID fixtures increased 89.7%.

Electric lamps are unique as a building product in that they are a consumable product intended for use for a relatively short period of time and requiring subsequent replacement, and as a result, only 15% of the electric lamps manufactured are intended for new construction end uses. For 1975, the 15% going to new construction is even less, because new construction volume has been severely depressed. ADL estimates that the percent of electric lamp sales which went toward new construction was less than 10%. Thus, there is a built-in cyclicality for the total shipments of electric lamps of 5-10% as a function of new construction volume. This cyclicality of 5-10% is markedly less than that of other building products which have a higher percentage of their sales going to new construction.

The residential and commercial sectors consume generically different types of lamps. Most residential illumination is provided by incandescent lamps, much of it portable incandescent light fixtures, traditional table lamps, floor lamps, etc. Of the 1.6 billion incandescent light bulbs manufactured in 1974, approximately 1 billion went to residential end uses, 400 million to nonportable fixtures. ASHRAE 90 will probably not impact the usage of these lamps. Fluorescent, on the other hand, is primarily a commercial illumination source. The commercial fluorescent market is almost entirely installed fixtures which ASHRAE 90 will indirectly regulate.

TABLE VII-16

SHIPMENTS OF ELECTRIC LAMPS USED IN THE ILLUMINATION OF BUILDING

(millions of units/dollars)

	1967		1972		1973		
Product Line	Bulbs	Value	Bulbs	Value	Bulbs	Value	B
Incandescent	1398.6	263.2	1697.5	380.0	1716.9	401.3	15
General Lighting							
15-150 watts	994.6	123.0	1227.0	184.1	1245.2	188.9	11
over 150 watts	65.0	18.4	69.3	24.2	67.0	23.9	
Fluorescent	233.8	166.5	293.3	232.3	307.2	245.1	2
Slimline	41.2	40.7	54.2	58.7	54.8	59.9	
Circular	5.9	9.3	5.2	9.9	5.5	10.3	
Other							
Below 40 watts	36.5	22.2	45.0	34.5	43.4	34.6	
Above 40 watts	134.3	71.0	166.5	91.9	180.3	101.2	1
TOTAL, all electric lamps[1]		781.8		1083.4		1120.0	

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[1] Excludes photographic, automobile, sealed beams, miniature electric discha
Christmas tree lamps.

SOURCE: Census of Manufacturers, 1972; Current Industrial Reports, 1974 Summa
Arthur D. Little, Inc., estimates.

TABLE VII-16

IPMENTS OF ELECTRIC LAMPS USED IN THE ILLUMINATION OF BUILDINGS

(millions of units/dollars)

	1967		1972		1973		1974	
	Bulbs	Value	Bulbs	Value	Bulbs	Value	Bulbs	Value
	1398.6	263.2	1697.5	380.0	1716.9	401.3	1532.0	398.9
ng								
	994.6	123.0	1227.0	184.1	1245.2	188.9	1110.5	182.3
ts	65.0	18.4	69.3	24.2	67.0	23.9	53.7	20.8
	233.8	166.5	293.3	232.3	307.2	245.1	284.5	246.0
	41.2	40.7	54.2	58.7	54.8	59.9	47.4	57.4
	5.9	9.3	5.2	9.9	5.5	10.3	6.1	13.2
ts	36.5	22.2	45.0	34.5	43.4	34.6	40.1	36.0
ts	134.3	71.0	166.5	91.9	180.3	101.2	170.7	102.9
ic lamps[1]		781.8		1083.4		1120.0		1176.5

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ographic, automobile, sealed beams, miniature electric discharge,
e lamps.

f Manufacturers, 1972; Current Industrial Reports, 1974 Summary;
. Little, Inc., estimates.

4. Product Trends

While incandescent and fluorescent lamps will continue to dominate the market, high intensity discharge lamps, which have a small share of the total building illumination lamp market, are expected to take increasing market share due to their higher efficiency.

Prior to the energy crisis and oil embargo, sales of both fluorescent and incandescent lamps were increasing at 4-5% per annum. The effect of the oil embargo and subsequent conservation practices was immediate and direct on lamp manufacturers, causing a decline in sales of approximately 15%. In commercial applications, it appears that one or two fluorescent tubes in any given fixture will continue to be disconnected to reduce what is considered by many to be "unnecessary" lighting. In residential applications, homeowners will be only slightly more careful about turning off lights when not in use, and will tend to substitute smaller wattage lamps (i.e., replacing 100 watt lamps with 60 watt lamps) in a further effort to conserve power.

5. Methods of Distribution

The residential market is serviced through wholesalers who typically distribute lamps and other electrical products only secondarily. Sixty percent of the lamps are sold to warehousing retail chains, some of which (industrial discount stores) are large enough so that they receive truckload shipments direct. Smaller chains and independents are serviced by grocery wholesalers, cooperatives, or hardware wholesalers.

The industrial commercial market is served primarily by wholesalers who specialize in their market and sell to contractors or building maintenance professionals. The wholesalers receive their lamps direct from company salesmen of each of the big three lamp manufacturers.

At the manufacturers' level, price is not a competitive weapon between lamp manufacturers. Each manufacturer publishes a list with quantity discounts and specified discounts for different people in the marketing chain. These prices are almost always comparable between manufacturers.

6. Quantitative Impact of ASHRAE 90

It is estimated that ASHRAE 90 will result in an average reduction of 23% in designed wattage per square foot in commercial buildings. The impact will be decidedly different on demand for incandescent versus fluorescent or high intensity discharge lamps, however, because of several factors.

The projected impact of ASHRAE 90 will be to reduce the wattage per square foot of installed electric lamps. As mentioned earlier, the incandescent market is primarily residential, and the bulk of that market is primarily portable. Of the one billion electric lamp incandescent light bulbs which are sold into the residential market each year, only

35-40% are in permanent fixtures and thus are vulnerable to regulation by ASHRAE 90. Most of the remaining 600 million bulbs consumed in nonresidential applications will also be affected, but it is estimated that only two-thirds, or 400 million, will be used in applications affected by ASHRAE 90. Thus, 800 million incandescent light bulbs produced each year would be affected by ASHRAE 90, 15% of which go to new construction. Assuming only 15% of the 800 million light bulbs sold for installation in nonportable fixtures will be affected by ASHRAE 90, the effect will be a 23% reduction in shipments, or a decrease of 28 million light bulbs worth $7 million. This accounts for but 1.7% of present domestic consumption.

As the building stock is gradually renewed over time and new buildings are built to conform with ASHRAE 90, replacing older buildings equipped to use more lamps, the long term effect will be to reduce the total consumption of incandescent bulbs by reducing the potential replacement market in commercial construction. Because half of the incandescent electric lamps sold are in portable fixtures or in nonbuilding applications, and thus not affected by ASHRAE 90, shipments will be reduced by 11.5% assuming uniform and complete enforcement of the standards, no substitution by fluorescent of HID, and no growth in the total square footage of the building inventory.

Virtually all fluorescent lamps are installed in permanent fixtures and the vast majority of these fixtures are in commercial buildings, and under the preview of ASHRAE 90. The 15% of the fluorescent tubes used in new construction will be reduced by 23%, so there will be a reduction in total fluorescent lamp shipments of approximately 3.5%, or 9.8 million lamps, worth $8.5 million.

No effort was made to quantify the impact of ASHRAE 90 on HID shipments in part because no good data exists on their sales volume, and in part because there will be substantial incentive to substitute HID lamps for fluorescent or incandescent to achieve greater illuminating efficiency, thus decreasing HID lamp sales. Many HID lamps are used in outdoor applications and as such are only marginally impacted by ASHRAE 90.

Among building products, the electric lamp industry is uniquely insensitive to fluctuations in new domestic construction activity because only a minor percentage of total products are destined for new construction. Presuming a possible volatility in the level of construction activity of 50% between the peaks and the troughs of domestic construction activity, the severity of the impact will fluctuate by 50% as well. Because the impact in a normal year is in the 20% range, the reasonable range of the impact as a function of construction activity would be 1% to 5%, still minor compared to industry shipments as a whole.

7. Qualitative Impact of ASHRAE 90

ADL believes the impact ASHRAE 90 will have on the lamp industry will be further lessened for several reasons. First, the manufacturers of incandescent and fluorescent lamps are among the largest multi-dimensional, diversified corporations in America and the levels of shipments will scarcely be felt.

Second, there will be a tendency to substitute fluorescent lamps for incandescent in new applications due to the greater efficiency of fluorescent lamps. HID lamps will be substituted for fluorescent in many applications as well. This will be particularly true in factory lighting and other situations where an accurate and complete color spectrum is not necessary and where large areas must be illuminated. While no attempt has been made in this report to quantify the impact to HID manufacturers, the long term effect will probably be beneficial.

Third, although the impact of ASHRAE 90 will be to erode fluorescent lamp shipments by 3.5%, the total square footage of commercial buildings inventory has been growing at an annual long term rate of approximately 3%, which, if this trend continues, should effectively compensate for the negative impact of reduced wattage per square foot required by ASHRAE 90.

Reduced sales of incandescent bulbs due to ASHRAE 90 will also be mitigated by the continuing compound growth in square footage of residential buildings of about 1% per year and of commercial buildings at 3% per year. The decline in incandescent lamp shipments of approximately 1.7% due to ASHRAE 90 will effectively be cancelled by additions of new square footage to the building inventory.

Finally, it is necessary to compare the potential impact to the lamp manufacturers of ASHRAE 90 with the impact of the oil embargo and energy crisis in 1973. Due to conservation efforts on the part of homeowners and commercial building owners, electric lamp sales, both fluorescent and incandescent, fell 15% overnight as building owners reduced the number of electric lamps in service. This abrupt but one time phenomenon had a considerably greater impact than the potential impact of ASHRAE 90 with a much smaller percentage decrease in shipments.

F. IMPACT ON LIGHTING FIXTURES MANUFACTURERS

1. Product Definition

Lighting fixtures include the bracket or holder to which the electric lamp and wires are attached, and where necessary, insulation, built-in switches, weatherproofing, etc. Annual shipments are reported by the Department of Commerce and include portable and nonportable residential fixtures and commercial fixtures.

Portable fixtures such as table and floor lamps, desk lamps, etc., are responsible for the majority of market volume and are excluded from further discussion as they are not covered under ASHRAE 90. Nonportable fixtures are 39% of total shipments, and reported commercial fixtures are almost entirely fixed.

2. Industry Characterization

There are numerous manufacturers of lighting fixtures in the United States most of whom specialize in one particular type of fixture. The industry is subdivided into several generic categories, such as indoor or outdoor, incandescent or fluorescent and commercial or residential. Very few of the manufacturers produce fixtures for more than one of these categories. Within each of these, the largest manufacturer typically has between 20-30% share of market, and beneath these industry leaders there are typically 10-20 smaller manufacturers.

This industry is characterized by ease of entry, particularly in the fluorescent fixture market where the principal manufacturing process is simply metal bending and where electrical components, wire, etc., are purchased from outside sources. It is not difficult for a firm with only a manufacturing capability to enter the industry, particularly if the firm is already manufacturing a product moving through parallel distribution channels.

Firms as a whole tend to be highly specialized in the lighting fixture industry. Ninety percent of the sales volume of commercial lighting fixture manufacturers in 1972 was from sales of commercial lighting fixtures. The residential lighting fixture industry was even more concentrated with 98% of their sales within this industry, suggesting that both of these industries contain firms who are highly dependent on the success of their industry as a whole.

3. Market Analysis

Shipments of commercial and residential lighting fixtures have grown steadily over the last decade, with the possible exception of 1974 in the residential sector. In seeking to aggregate lighting fixtures in meaningfully large groups, it is not possible to compare units because of the great variety between units within a single aggregated category, so the only useful data available is dollar volume of shipments. Table VII-17 shows that residential shipments increased from $190 million in 1967 to $285 million in 1972 and $323 million in 1974. Commercial and industrial fixtures (used for general lighting), also portrayed in Table VII-17, increased from $506 million in 1967 to $839 million in 1974.

The vast majority of all lighting fixtures are sold to new construction electrical subcontractors. With the present slowdown in new construction activity, however, an increasing percentage of shipments (estimated to be presently 15%) are being used in remodeling applications which are not directly classed as new construction.

Residential fixtures are primarily incandescent, but fluorescent fixtures, which are only a small fraction of the total residential market, are growing at a rate faster than the market as a whole or incandescent fixtures in particular.

TABLE VII-17

SHIPMENTS OF LIGHTING FIXTURES

(Millions of Dollars)

	1967	1972	1973	1974
TOTAL RESIDENTIAL[1]	457.8	737.2	na	na
Non-portable Fixtures	190.5	285.4	336.6	322.7
Incandescent				
Interior	141.0	223.6	257.0	246.1
Outdoor	28.0	44.6	55.5	55.8
Fluorescent	11.5	19.7	24.0	23.8
Portable Fixtures	176.3	317.5	na	na
TOTAL COMMERCIAL	385.4	497.9	566.9	654.0
Incandescent	92.5	123.2	145.1	156.8
Fluorescent	303.1	374.3	410.4	481.7
Mercury and HID	na	4.6	11.4	15.5
TOTAL INDUSTRIAL	120.6	154.1	162.1	185.9
Incandescent	13.4	5.9	6.7	7.6
Fluorescent	62.8	71.8	74.5	78.2
Mercury, HID, and Other	35.1	68.5	80.7	100.0

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[1] Including fixtures not elsewhere classified.

SOURCE: Census of Manufacturers, 1972
Current Industrial Reports, 1974

The commercial market on the other hand, is primarily fluorescent, with fluorescent having three times the sales volume of incandescent. In the industrial market, fluorescent is favored 11 to 1 over incandescent. The fastest growing segment of both the commercial and industrial markets. is the HID market, which has doubled in volume from 1972 to 1974 and increased five-fold since 1967.

The square footage of commercial buildings put-in-place in 1974 was 12-13% less than 1973 levels. Despite this fact the dollar value of shipments of commercial lighting fixtures increased 17% during this period. Actual unit sales of most individual items also show a small increase although some of this substantial 17% increase was certainly due to inflation.

4. Product Trends

The present recession in the construction industry has slowed the growth rate of these industries and the demand for their products. Prices for these products have tended to increase at approximately the rate of inflation or somewhat less because there are many competitors in the lighting fixture market and competitive pressures keep the prices low, so much of the growth in dollar volume of shipments can be equated to an actual increase in number of units shipped.

5. Methods of Distribution

The distribution channels for residential and commercial lighting products is common to virtually all manufacturers. From the manufacturer, products are sold to wholesalers through independent manufacturers' representatives who generally carry several noncompeting manufacturers' lines. Wholesalers in turn, sell to contractors, consumers, or retail outlets such as grocery stores, hardware stores, etc. Ninety-five percent of the commercial fixtures and 90% of the residential fixtures are sold direct to contractors or force account electricians. The remaining percent in each case is sold for remodeling applications to the homeowner or plant owner.

6. Quantitative Impact of ASHRAE 90

ADL estimates that ASHRAE 90 could cause an immediate 21% reduction in the number of fixtures sold to the combined residential, commercial, and industrial fixture markets in new construction. Because ASHRAE 90 does not deal with remodeling or alterations, to which 15% of the fixtures are sold, the impact on total sales volume will be an 18% reduction. Based on this, shipments of residential nonportable fixtures should decline by an estimated $58 million from a 1974 level of $323 million due to ASHRAE 90. Similarly, the commercial and industrial market can be expected to lose $117 million in sales based on a selling volume of $654 million in 1974. In an industry which has so many small specialized manufacturers, many in considerably weaker competitive positions than others, the likelihood of driving some of the weaker firms out of business is considerable.

7. Qualitative Impact of ASHRAE 90

Two factors will affect, and in some cases mitigate, the apparent impact of ASHRAE 90 on lighting fixture manufacturers. More efficient lighting forms will replace less efficient forms in new and renovation construction heightening the impact of the standard on manufacturers of components of the less efficient forms, and diluting the impact on manufacturers of the more efficient forms. It is expected that substitution of HID lamps for fluorescent and incandescent lamps will continue due to their immediate operating economies and greater illuminating efficiencies. Similarly, fluorescent lighting is expected to grow at the expense of incandescent, because it is expected that in new construction, architects will design the most efficient lighting type available wherever possible. This shift in market share of the lighting technologies will adversely affect shipments of incandescents and increase shipments of HID.

It appears that the energy crisis has created sufficient economic incentive for owners of existing buildings to convert their present incandescent or fluorescent fixtures to more efficient fluorescent or HID fixtures and thus reduce their electrical bills. This conversion market is apparently large enough to more than compensate for the expected reduced demand for lighting fixtures due to the 12-13% decline in new commercial construction. Thus, projected declines in consumption of commercial lighting fixtures due to ASHRAE 90 may be largely compensated for by increased sales of lighting fixtures for existing construction or renovation work. Industry sources report that the lighting fixture industry has moved from being 95% dependent on new construction to 85% or less. These two rapidly growing market sectors would appear to be cyclical in the case of lighting-type conversion and perhaps anti-cyclical in the case of remodeling and would therefore tend to directly compensate and mitigate the impact of ASHRAE 90 on the fixture industry as a function of new domestic construction.

Finally, most commercial and industrial buildings have a time lag from the time of initial design and system specification to the actual installation of the lighting fixtures which can be as great as two years. Residential design time lag is probably six to nine months. It is very unlikely that new buildings already designed and specified will be subsequently modified to use more efficient lighting fixtures than were originally included in the design to comply with ASHRAE 90. Thus, the principal impact of ASHRAE 90 will not be felt immediately in either the commercial or residential sector, but rather twelve to eighteen months after implementation.

G. IMPACT ON GAS AND ELECTRIC METER MANUFACTURERS

1. Product Definition

Meters are installed to monitor the flow of natural gas or electricity provided by public utilities or municipal authorities. While some data on gas meter shipments are compiled by the Department of Commerce, the secrecy and competitiveness of the industry prevents the government from compiling accurate statistics. Electric meters offer no such problem.

There are four types of gas consumption meters: diaphragm, rotary, turbine and orifice. The selection of which type of meter to use is a function of price, maximum flow rate of gas, and minimum volume or sensitivity. The diaphragm meter is the preferred meter for most residential applications and is generally limited to a capacity of 200-400 cubic feet per hour. Models with higher flow rate capacities are available for commercial end uses. For commercial users of large volumes of gas in excess of those easily measured by the diaphragm type meter, a rotary meter is often used. This meter uses a double helical screw and measured moderate sized flows of gas. Turbine and orifice meters are used in very high flow rate applications such as industrial furnaces, electric generating stations, etc., and as such are not relevant to this study.

Likewise, there are three types of electric meters: single-phase, poly-phase, and demand meters. Single-phase meters are used principally for residential or small commercial applications and are the basic meter of the industry. Poly-phase meters are typically used with 208 or 440 volt, three-phase power, in large commercial buildings or apartment complexes. Demand meters can be either single- or poly-phase, and measure not only the total kilowatt hours consumed during a period but also the peak power demand which occurred during the time period.

2. Industry Characterization

The technology of manufacturing meters is well established and has undergone few changes in the last decade. Success in the industry is achieved by having sufficient volume and fixed plant investment to manufacture meters at a low enough per unit cost to be profitable at the relatively low per unit prices.

There are three principal and three minor manufacturers of gas meters in the United States. Their competitive positions can only be estimated, because market share, profitability, sales, etc., are closely guarded. Furthermore, the residential and commercial meter markets utilize generically differenct meters, diaphragm versus rotary, so it is not completely correct to consolidate their manufacturers' sales, etc.

The largest firm is estimated to have a 45% share of market. Four of the six firms are divisions of large diversified manufacturing firms, and as such have access to sizable capital resources with which they can finance any change in product or manufacturing technology. Only one firm manufactures gas meters exclusively, assembling complete meters and replacement parts.

Concerning AC watt hour meters, there are four principal manufacturers with the largest having approximately a 40% share of the market. The second and third largest each have about 25% of the market.

3. Market Analysis

Table VII-18 shows the shipments of gas meters in the United States for the last several years. Gas meter shipments have declined from their

TABLE VII-18

METER SALES

(Thousand Units)

	1967	1972	1973	1974
Total Gas Meters Production	1,400	1,450	1,500	1,300
New Customers[1]	900	900	950	800
Commercial	100	100	100	100
Replacements	400	450	450	400
Total Sales (millions of dollars)	57.6	69.7	70.0	65.0
Residential	--	45.0	50.0	46.0
Electric Meters				
Total Production	4,173	5,387	5,741	5,288
Single-Phase Meters	3,416	4,710	4,946	4,407
Poly-Phase Meters	362	330	403	464
Demand Meters	396	347	392	417
Total Sales (millions of dollars)	65.2	174.7	125.0	127.3

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[1] Includes new residential construction and conversion from oil or electric space heating.

SOURCE: Construction Reports, Department of Commerce 1973
Census of Manufacturers, 1972
Gas Facts 1970-1973
Current Industrial Reports, 1973 and 1974
Arthur D. Little, Inc., estimates.

1973 peak due to the proliferation of moratoria for new gas connections for residential and commercial buildings, which has caused many new building owners to substitute oil or electricity. Similarly, construction industry volume has declined since 1973, worsening the decline in total new gas connections and with it the demand for new meters.

Based on reliable industry sources, shipments of all types of gas totalizing meters for residential, commercial, and industrial buildings will be approximately one million units in 1975. Only 5-10% of this total number is used in commercial applications, but commercial meters represent 25-33% of the value of industry shipments. Prices of gas meters average $37-38 per unit today, whereas large commercial rotary or turbine meters sell for $1,500 on average. Approximately 400,000 units are used in replacement applications each year.

Several years ago one manufacturer tried to introduce a disposable meter which could not be tested, repaired or calibrated. It failed to gain acceptance in the marketplace, however, and today virtually all meters are repairable and, depending on state public utility commisssion regulations, are removed every ten years or so for testing, calibration, and refurbishing.

Turning to electric meters, Table VII-18 shows that annual sales volume of electric meters increased each year up to 1973 in all three meter categories. However, with the decline in residential housing starts beginning in late 1973, shipments of residential single-phase AC watt hour meters declined to about 12% in 1974 from 1973's peak. Single-family housing starts declined by more than 12% during this period however, and the smaller decline in meter shipments reflects the time lag between the recording of the housing start and the actual shipment of the meter (approximately twelve months) plus the increasing penetration of individual metering to master metering.

Virtually every new building has electrical service and thus must be metered, compared with a present penetration of natural gas in new housing starts of only 30%. Only 5% of the electric meters manufactured are intended for replacement applications, because current state-of-the-art manufacturing technology and the weathertight, airtight environment in which the units work provides a very accurate and very long-lived mechanism. Of the 4.4 million single-phase AC watt hours meters shipped in 1974, 0.2 million were replacement meters, 2.2 million were for new residential construction (including mobile homes) and 2.0 million units were consumed in commercial, industrial and renovation end uses.

4. Methods of Distribution

Gas meters are sold by manufacturers' salesmen direct to utilities Competition is on the basis of price and performance. Prices are usually very competitive and performance is a subjective feature, where the meter superintendents' opinions are the determining factor.

Utilities generally prefer to buy from more than one source of supply so they have longstanding relationships with each meter company. The market share of each manufacturer is therefore quite constant over time with each utility seeking to do a fixed percentage of its total purchases with each manufacturer.

Utilities also purchase the vast majority of electric meters. Only in rural locations where Rural Electrification Act (REA) utilities provide power and do not have the in-house capability to install meters and distribution systems will an electrical contractor actually purchase and install the electric meters. The typical electric utility will do business with at least three of the four manufacturers once a year. As a result the manufacturer's sales representatives are less important in selling the product than established sales history. In order for a utility to use an electric meter that meter must typically be approved by the state Public Utilities Commission. Thus, it is difficult for a new manufacturer to enter the market, and the share of market of each of the major manufacturers has been fairly stable over the last several years.

5. Quantitative Impact of ASHRAE 90

ASHRAE 90 specifies that some method be developed to measure the consumption of the utility by each individual tenant. For purposes of this study, it is assumed that the only way to comply with this requirement will be to install individual gas and electric meters, thereby eliminating the practice of master metering, wherein a utility is measured for the entire building and not on a tenant-by-tenant basis. Because a certain portion of new construction is presently master metered, replacement of these relatively few master meters by a greater number of individual meters, should create a somewhat larger market for gas and electric meters.

Over the last decade, the practice of master metering residential units has become widespread in many areas of the country. The decision to master meter and therefore include the cost of utilities in the rent is primarily a competitive one based on forces within the rental market. Comparatively few commercial units are master metered; however in some climates where air conditioning or heating is particularly necessary, or the design and configuration of the building makes it impossible to accurately assess the heating or cooling load of any individual tenant or to allow him to control this load, it is more common.

Over the last five years, there has been a trend away from master metering in the Northeast and North Central regions in particular, where rapidly rising utility rates have increased utility costs, and wage and price controls or rent control have made it difficult for landlords to pass the increased cost of utilities along to their tenants. However, a substantial part of the new construction in the United States has been in the Southeast and West South Central region where energy has been traditionally cheap and plentiful and there has been a high air conditioning load. Thus, the rapid growth of construction in these regions has tended to keep the penetration of master metered buildings nationwide at an equal level.

Approximately one-third of all multi-family units in buildings with five or more units are electrically master metered. Similarly, ADL estimates that 50% of the units with natural gas available to multi-family buildings with three or more units are master metered. Since early 1974, however, the rapid increase in costs has severely affected the economics of many master metered rental projects throughout the country, with the result that there is now a broad move away from master metering in all areas of the country and a corresponding decrease in the penetration of master metered units in new starts from 1974 to the present. If anything, the adoption of ASHRAE 90 will further enforce the trend away from master metering.

In 1970 there were 6.2 million gas heated units in multi-family buildings with three or more units per building. It is estimated that 50%, or 3.1 million of these units were master metered. This penetration was little changed through 1973, when for example, there were 140,000 new master metered units added to the inventory. By 1974, however, gas moratoria reduced the number of multi-family starts with gas as a heating fuel to only 32% or about 200,000 units in buildings with three or more units per building. Assuming that the percent of the units which were master metered fell to 40%, the total number of master metered units added to the inventory was only 80,000. Through July of 1975, with worsening gas moratoria and a severely depressed multi-family housing construction market, only 126,000 units were started in buildings with three or more units per building. The penetration of gas in these buildings was only about 30% and only one-third of the units, it is estimated, were master metered. Thus, the total number of master metered multi-family units added to the inventory through July of 1975 was only 13,000.

Assuming 400,000 multi-family units will be constructed in 1976 and taking into account the time lag of 12-18 months from the recording of the start to installation of the gas meter, ADL estimates that approximately 40,000 new gas heated master metered units per year would be built in the absence of ASHRAE 90. Thus, the impact of the standards in requiring the use of individual meters for all new construction would be to increase the shipments of gas meters by close to 40,000 units, or approximately 4% over 1975's projected shipments of one million units, or 3% over 1974 levels of 1.3 million. Increased shipments of 40,000 units represents an increase in sales revenue of about $1.6 million. Mitigating this increase somewhat would be a reduction in shipments of larger "master" meters of 2,000 to 5,000 units.

Regarding electric meters, approximately one-third of all residential units in buildings with five or more units are master metered. In 1973, approximately 290,000 new multi-family units were built with electrically master metered units. In 1974 this number fell to 140,000 due to the dramatic decline in the construction of new multi-family starts. In 1975 through July only 126,000 multi-family units had been built in the five or more size range. The slowdown in construction, particularly in the former high growth/cheap fuel markets, such as Houston, Dallas, etc., probably reduced the penetration of master metering to only 20%. So, the present addition to the housing inventory of master metered units through July of 1975 would be only 25,000 units. Due to the accelerating rate of construction during the latter half of 1975, the number of units added with master metering will probably approach 60,000 units for the year, presuming a total multi-family market of 300,000 units. Projecting 400,000 multi-family units for 1976, approximately 80,000 of these units would be master metered in the absence of ASHRAE 90. Due to the standard, these units will be individually metered and this increase in shipments of 80,000 meters would result in an increase in shipments over 1974 levels of 1.8%, or $1.2 million. With the substitution and replacement of larger meters by the smaller individual tenant meters, the loss in sales of larger meters will prbably not exceed 10,000 units.

Interestingly, the gradual conversion of the present inventory of approximately 3.4 million electrically master metered multi-family units would represent a larger opportunity for meter manufacturers than the new construction market. Based on a conversion rate of only 3% per year, 125,000 new individual meters will be required annually to satisfy this market. Similarly, a conversion rate of 3% per year would also result in an additional 100,000 unit annual demand for gas meters.

6. Qualitative Impact of ASHRAE 90

It appears that ASHRAE 90 will have little impact on the electric meter manufacturing industry. Industry sales are more seriously affected by the overall health of the construction industry, as shown by the decline of 500,000 units from 1973 to 1974, than they will be by ASHRAE 90. Other suggested energy conservation action could also affect electric meter sales as well. Experiments are being conducted with time of day metering and demand metering to determine if these will help reduce load factors and provide incentives to encourage conservation by consumers. In addition, to reduce the cost of reading meters scattered over the countryside, efforts have been made to develop a meter which could be read by remote sensors. If any of these changes occur, the conversion from master meters to individual meters will be comparatively insignificant.

Similarly, the net increase in sales of gas meters due to ASHRAE 90 is small in comparison to the erosion in sales volume over the last three years due to the energy situation, gas moratoria, and/or the level of construction activity. ASHRAE 90 will provide a mild stimulus to the gas meter manufacturing industry.

H. IMPACT ON WATER HEATER MANUFACTURERS

1. Product Description

There are several different generic types of water heaters manufactured in the United States, each of which may be characterized by four basic parameters:

- Residential or nonresidential;

- Tank or tankless;
- Gas, electric, or oil fired;
- Storage capacity and/or rate of recovery.

Trends in the sales and shipments of different heater types are discernible by examining published government and industry sources. The two most accurate sources of market data are supplied by the Deparmtnet of Commerce (DOC) and the Gas Appliance Manufacturers Association (GAMA).

2. Industry Characterization

There has been a significant consolidation within the industry over the last ten years. Today there are only ten water heater manufacturers of any consequence compared to sixty to eighty a decade ago. The present concentration of the ten principal water heater manufacturers expressed as an approximate share of market for each is estimated to be as follows:

Manufacturer	Cumulative Percent Market
Top 1	25%
Top 3	64%
Top 5	83%
Total, 10 Suppliers	100%

While these ten manufacturers essentially control the total national market, the manufacturing technology of water heaters is simple enough that it is possible for a small manufacturer with a particularly advantageous marketing position to manufacture water heaters for a limited geographic market. Thus, several utilities assemble their own private label units for distribution to their customers. This practice is declining however. Previously the gas and electric utilities would compete by each having private label heaters. With the removal of gas for new hookups as a competitive force in the energy marketplace and the new emphasis on energy conservation, utilities are reducing their promotion of water heaters.

3. Market Analysis

Table VII-19 shows the shipments of household hot water heaters in 1967, 1972, and 1973, as reported by DOC. Total production in 1973 was approximately 5.7 million units of which 170,000, or 3% were commercial. Of the commercial, 90,000 were tank type and 80,000 coil or tube type. All the remaining water heaters were residential, and virtually all were direct-fired tank type with a storage capacity of between 30 and 52 gallons. According to government sources, 1973 was the first year that electric water heaters approached a 50% share of market. Electric water heaters have been steadily gaining market share over the last fifteen

TABLE VII-19

U.S. SHIPMENTS OF HOT WATER HEATERS, 1967-1973

Type and Volume	1967		1972		
	Thousands of Units	Millions of dolars	Thousands of Units	Millions of Dollars	Thousand of Unit
Electric					
Permanent Storage Type					
< 34 gallons	431.2	13.8	1025.8	35.5	1010.4
35-44 gallons	400.9	16.1	676.0	32.7	820.9
45-54 gallons	467.7	20.4	605.0	31.3	677.3
> 55 gallons	151.8	10.3	205.8	16.5	271.7
Circulating or Portable	20.0	2.6	22.0	3.0	26.3
Subtotal	1451.6	63.4	2534.6	119.0	2806.6
Nonelectric					
Direct Fired					
Gas	2871.8	118.7	3320.2	162.1	2861.2
Oil	13.5	2.0	15.6	3.2	28.9
Other, Including Indirect Fired	50.0	9.4	35.0	6.0	30.0
Subtotal	2935.3	130.1	3370.8	171.3	2920.1
TOTAL	4386.9	193.5	5905.4	290.3	5726.7

SOURCE: Department of Commerce, Census of Manufacturers, 1972. Current Industrial Reports
Arthur D. Little, Inc., estimates.

TABLE VII-19

. SHIPMENTS OF HOT WATER HEATERS, 1967-1973

1967		1972		1973	
Thousands of Units	Millions of dolars	Thousands of Units	Millions of Dollars	Thousands of Units	Millions of Dollars
431.2	13.8	1025.8	35.5	1010.4	39.3
400.9	16.1	676.0	32.7	820.9	39.6
467.7	20.4	605.0	31.3	677.3	36.4
151.8	10.3	205.8	16.5	271.7	20.4
20.0	2.6	22.0	3.0	26.3	3.6
1451.6	63.4	2534.6	119.0	2806.6	139.8
2871.8	118.7	3320.2	162.1	2861.2	139.5
13.5	2.0	15.6	3.2	28.9	4.8
50.0	9.4	35.0	6.0	30.0	5.2
2935.3	130.1	3370.8	171.3	2920.1	149.5
4386.9	193.5	5905.4	290.3	5726.7	288.8

rce, Census of Manufacturers, 1972. Current Industrial Reports (MA 36F);
nc., estimates.

years due to their ease of installation, gas moratoria which have moved builders toward electricity in many regions.

Table VII-19 also lists shipments of electric water heaters according to size. From 1967-1972, there was a significant shift toward smaller water heaters. Historically, electric water heaters required greater storage capacity because of their slower recovery rate, but now, due to larger heating elements it is possible to store less water and recover it more quickly in smaller sized units.

It is estimated that 60% of the residential hot water heaters manufactured go to replacement applications, the balance being for new home construction.

4. Methods of Distribution

Seventy to eight percent of all water heaters are marketed through wholesalers. Virtually all are installed by plumbers and in some code jurisdictions a gas fitter may be required for gas heaters or an electrician for electric. These extra trades are required only for a new construction or conversion; replacement typically can be done by a plumber single-handedly.

Mass merchandisers are a major outlet of water heaters, accounting for approximately 1,000,000 units per year. Adding this to the 500,000 units which were installed in mobile homes in 1973, the total number of heaters moving through wholesalers and plumbers totals approximately 4.2 million units.

Consumer influence in brand choice is virtually nil; the plumber controls it almost completely but plumbers generally have no pronounced loyalties to any particular brand either. Their loyalty is more to the plumbing supply house and they will generally acept any brand which the wholesaler handles. It is the wholesaler who gives the performance guarantee for the product and it is to him that the plumber will turn for replacement should the product fail. When wholesalers switch brands, they are generally able to convert better than 90% of their plumbers to the new line.

5. Economic Impact of ASHRAE 90

The major impact due to the adoption of ASHRAE 90 will be to set certain minimum performance requirements on water heaters. This may or may not result in higher equipment costs depending upon how water heater manufacturers choose to meet the standard.

Table VII-20 summarized the performance standards required to ASHRAE 90 both now and beginning in January 1977, and compares this to the typical performance of presently available units. Also shown are several alternative remedial measures which could be taken to meet the standard accompanied by their estimated cost per unit.

TABLE VII- 20

ESTIMATED UNIT COST TO WATER HEATER MANUFACTURERS IN MEETING ASHRAE 90-75

Applicable Section In ASHRAE 90	ASHRAE Criterion (Current)	ASHRAE Criterion (January 1, 1977)	Typical Performance of Current Units	Remedial Measure
7.3.1.1	Standby loss of electric heaters not to exceed 6 w/ft^2.	Standby loss of electric heaters not to exceed 4 w/ft^2.	3.7 w/ft^2 *	None.
7.3.1.2	For gas and oil fired heaters, recovery efficiency (Er) $\geq$ 70%.	Er $\geq$ 75%.	Er = 72%.	Alternatives: • Reduce excess air from 75% to 50%. • Increase flue baffling.
	S $\leq$ 6%/hr.	S $\leq$ 4%/hr.	S = 5%	Alternatives: • Reduce thermostat setting from 150 to 140°F. • Increase insulation from 3/4" to 1". • Cut pilot rate from 750 to 500 Btu/hr.
7.3.2	Space heater cannot be used as water heater. Exemption to units having standby loss $\frac{25\ PMD + 250}{n} = 1750\ \frac{Btu}{hr}$	Space heater cannot be used as water heater. Exemption to units having standby loss $\frac{13.3\ PMD + 400}{n} = 1460\ \frac{Btu}{hr}$	Typical domestic boiler has PMD = 25 gph and n = .5. Standby loss is 400 to 700 $\frac{Btu}{hr}$ for 40 gallon storage	None.
7.3.3	Standby loss of unfired tank must be less than 15 Btu/hr-ft.^{2}	-	12.7 Btu/hr ft.^{2}*	None.
7.4	Thermostat for 105 to 180°F adjustment.	-	All units adjustable at factory. Some units not adjustable by the homeowner.	None.
7.5	Shut off switch.	-	Provided.	None.
7.6	Pump shut off.	-	Provided.	None.

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*Based on 1-3/4" fiberglass insulation, air film coefficient, and temperature differential of 100°F (worst cas

TABLE VII-20

ESTIMATED UNIT COST TO WATER HEATER MANUFACTURERS IN MEETING ASHRAE 90-75

RAE Criterion (Current)	ASHRAE Criterion (January 1, 1977)	Typical Performance of Current Units	Remedial Measure	Estimated Unit Cost
y loss of elec- eaters not to 6 w/ft^2.	Standby loss of electric heaters not to exceed 4 w/ft^2.	3.7 w/ft^2 *	None.	0
s and oil heaters, ry efficiency = 70%.	Er ≥ 75%.	Er = 72%.	Alternatives:	
			• Reduce excess air from 75% to 50%.	0
			• Increase flue baffling.	$0.50
/hr.	S ≤ 4%/hr.	S = 5%	Alternatives:	
			• Reduce thermostat setting from 150 to 140°F.	0
			• Increase insulation from 3/4" to 1".	$0.80
			• Cut pilot rate from 750 to 500 Btu/hr.	$1.00
heater cannot d as water . Exemption to having standby $\frac{\text{MD} + 250}{n}$ 750 $\frac{\text{Btu}}{\text{hr}}$	Space heater cannot be used as water heater. Exemption to units having standby loss $\frac{13.3\ \text{PMD} + 400}{n}$ $= 1460\ \frac{\text{Btu}}{\text{hr}}$	Typical domestic boiler has PMD = 25 gph and n = .5. Standby loss is 400 to 700 $\frac{\text{Btu}}{\text{hr}}$ for 40 gallon storage	None.	0
y loss of un- tank must be han 15 Btu/hr-ft.^{2}	-	12.7 Btu/hr ft.^{2}*	None.	0
stat for 105 to adjustment.	-	All units adjustable at factory. Some units not adjustable by the homeowner.	None.	0
ff switch.	-	Provided.	None.	0
hut off.	-	Provided.	None.	0

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insulation, air film coefficient, and temperature differential of 100°F (worst case).

In general, it appears that the increase in cost of presently available water heaters due to ASHRAE 90 will be small. If the most costly options are adopted, typical water heaters will increase only $1.50 in cost. Even allowing for some markup on behalf of the manufacturer, the incremental price to the consumer will be on the order of 3% maximum. This would result in no economic impact to the wholesaler, or the plumber, and would be carried directly through to the consumer.

Based on $1.50 per unit, the maximum impact on water heater manufacturers to comply with ASHRAE 90's 1977 requirements will be an increase of about $4 million in market size. Manufacturers will probably choose to upgrade their entire water heater line, rather than just those units intended for new construction, and that this will result in an impact of $11 million, or about 3.9% of annual sales.

Finally, it should also be noted that recovery efficiency called for in the standard by January 1977 (Er ≥ 75%, S ≤ 4%/hour) are nearly equal to the voluntary energy savings objectives (Er ≥ 80%, S ≤ 4%/hour) set by FEA to be met before 1980. We anticipate that water heater manufacturers will adopt the FEA guidelines by that time, and in doing so will exceed ASHRAE 90's requirements by 1980.

Another impact of ASHRAE 90 will be to replace shower heads, which now generally vary between 5 to 10 gpm, with fixtures limiting flow rates to 3 gpm. There is no incremental cost of meeting this criterion. Also, controls are available for maintaining swimming pool temperatures to less than 80°F where current settings vary between 75°-85°F.

I. IMPACT ON HVA/C EQUIPMENT MANUFACTURERS

1. Product Definition

An overall definition of the HVA/C industry would include both equipment suppliers and installers, the most prominent of which are mechanical contractors. HVA/C equipment suppliers can be either manufacturers who offer components which are assembled off-site and whose configuration is not dependent upon the type of building in which it is eventually used, such as a residential warm-air furnace, or companies that supply components that are fabricated on-site or for a particular job, such as air distribution systems. For purposes of this study, the HVA/C industry will be confined only to off-site assembled equipment, and in particular. HVA/C equipment which is supplied primarily for controlling the interior environments of buildings.

The HVA/C equipment industry consists of an extremely wide variety of products as Table VII-21 indicates. Furthermore, these products represent a broad range of sophistication--from centrifugal chillers and multizone air handling units to blowers and vibration mounts. Some of these products could be considered "commodities" because of their low cost, their relatively

TABLE VII-21

SELECTED HVAC PRODUCT LINES

Accumulators
Acoustical Ductwork
Adsorbers, Odor
Air Cleaning Equipment
Air Compressors
Air Conditioners, Central Station
Air Conditioners, Roof-Mounted
Air Conditioners, Self-Contained
Air Conditioning Fan Coil Units
Air Conditioning, Multi-Zone
Air Distribution Systems
Air Diffusers
Air Filters
Air Mixing Units
Air Turning Vanes
Air Washers
Automatic Shutters
Automation Controls, Electronic, Pneumatic
Axial Flow Fans
Barometric Draft Controls
Blower Housings
Blowers, Heating and Ventilating
Boiler Feed Pumps
Boilers
Burners
Check Valves, Refrigerant
Chillers, Liquid or Water
Chimney Systems
Circulators, Hot Water Heating
Coils, Cooling and Heating
Compressors, Refrigeration
Condensers, Air-Cooled
Condensers, Evaporative
Condensers, Water-Cooled
Control Equipment, Electric
Controllers, Pneumatic
Convection Heaters
Cooling Tower Fans
Cooling Tower Silencers
Cooling Towers
Crankshafts
Cryogenic Equipment
Dampers, Air Volume Control
Dehumidifiers
Doors, Access
Dual-Duct Systems
Duct Silencers
Ejectors
Electrostatic Precipitators
Evaporative Coolers
Exhaust Heads
Expansion Loops
Fan Blades
Fan Silencers
Fans, Axial Flow
Fans, Centrifugal
Fans, Propeller
Filter Replacement Cartridges
Fire Detectors
Float Valves
Fuel Oil Preheaters
Furnaces, Commercial/Industrial
Furnaces, Warm Air, Heavy Duty
Furnaces, Warm Air, Residence
Gages, Pressure and Vacuum
Heat Exchangers
Heat Pumps
Heat Redistribution Systems
Humidifiers
Louvers, Solar Heat Control
Motor Bases
Motors
Plenums, Acoustical
Pressure Vessels
Pump-Motor, Combination
Pumps, Automatic Reversing
Pumps, Centrifugal
Pumps, Variable Speed
Refrigerant Driers
Refrigerating Equipment, Absorption
Refrigerating Equipment, Centrifugal
Refrigerating Equipment, Reciprocating
Registers
Smoke Detector
Storage Water Heaters
Strainers
Switches, Pneumatic
Thermostats
Traps
Tubes and Tubing
Underground Pipe Conduits
Ventilators
Vibration Absorbers
Water-Cooled Lighting Fixtures

low degree of sophistication, or their ready availability. On the other hand, HVA/C components such as large tonnage refrigeration machines or large commercial cooling towers are manufactured on an as-ordered basis and usually are not kept in inventory. Generally speaking, those components of interest here encompass both of these extremes with commercial boilers, residential warm-air furnaces, and fan coil units being typical examples.

HVA/C equipment can generally be divided into two broad categories--unitary and applied. Unitary equipment is often referred to as "packaged" equipment, and is typically factory assembled. It is used in both residential installations (central A/C systems) and light commercial and industrial installations which lend themselves to such components as rooftop, self-contained air conditioners. Unitary equipment is typically sold through distributors and/or dealers, and may or may not be in need of an air distribution system (i.e., duct work) upon installation.

Applied equipment is defined to be those components which are selectively assembled in the larger field-engineered systesm. Such equipment lies virtually entirely within the nonresidential sector, and as opposed to unitary equipment which is sold through distributors, applied equipment is often sold direct.

2. Industry Characterization

ADL estimates there are over 700 companies which manufacture HVA/C equipment, however, only about 20 are significant in terms of their annual revenues. Concentration varies by type of equipment. Generally speaking, fewer manufacturers dominate the markets for applied, or field engineered equipment, as opposed to unitary equipment. As concentrated as the individual markets are, there is no concentration of the industry as a whole. For example, comparative market shares for unitary air conditioning equipment, commercial chillers, and all HVA/C equipment are as follows:

	Unitary A/C	Commercial Chillers	Total HVA/C Equipment
Market Leader	35%	40%	14%
Top Three Manufacturers	57%	85%	24%

Virtually all market participants, particularly the industry leaders, offer an integrated line of equipment ranging from central heating and/or cooling equipment to various types of nonresidential air handling equipment. Less than about one-third of the industry participants confine themselves to either residential or nonresidential construction, with manufacturers usually serving both sectors.

3. Market Analysis

Without a more extensive investigation of all of those product lines shown in Table VII-21, the size of the total market for mechanical equipment within the building industry can, at best, only be estimated. ADL estimates that the total annual sales for those mechanical components shown approached $5 billion in 1973, or about 4.5% of the estimated $120 billion which was accounted for by the construction industry that year. To this sum, of course, one must add the cost of labor and associated distribution componenets (i.e., ducts, pipes) which will make the percentage of the total considerably greater. Although the ratio between HVA/C equipment and labor varies according to system type, etc., a rough approximation of any mechanical contract might be 55% equipment and 45% labor.

Accurate statistics on shipments of various types of both unitary and applied HVA/C equipment are kept by the Air-Conditioning and Refrigeration Institute (ARI) on behalf of its members.[1]

Annual shipments of unitary air-conditioners (the single biggest component category of unitary equipment) are commonly used to measure the installed value of unitary equipment. Unitary A/C also has historically shown the strongest growth, although 1974 was a bad year for such equipment. There were approximately 1.9 million residential units shipped, accounting for 79% of installations versus a total for commercial installations of approximately 0.5 million or 21%. Export volume is minimal.

The 1974 figures are in marked contrast to those posted in 1953, the first year for which statistics were available, when 67% of total unitary shipments went into commercial installations and only 33% into residential. Since then, residential markets for such equipment have steadily drawn away from commercial installations due to the continually increasing saturation of central air conditioning systems in new single-family construction. As opposed to a decrease of 12% in unitary air conditioner shipments (2.8 million versus 2.4 million) the installed value[2] of such equipment during 1974 declined by only 5.8% from the installed value of $4,150 million to $3,910 million. The cyclical fluctuations in unitary equipment are generally greater than that of the installed value of the total systems as a whole.

In contrast to unitary systems, the installed value of applied, or field-engineered systems (e.g., multi-family residential and commercial systems utilizing applied equipment) put-in-place during 1974 showed a sharp gain (19%) from the 1973 figure. The installed value for 1974 was $2,340 million, and reflects the fact that field-engineered equipment is not dependent upon residential construction, and thus shows gains during those years when unitary equipment otherwise decreases. Table VII-22 shows comparative growth rates of unitary and applied HVA/C systems over the period 1960-75. Historically, the growth of all of these markets has exceeded the overall growth of both the construction market in general, and of GNP over the same period.

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[1] ARI's membership generally accounts for about 90-95% of actual shipments of domestic HVA/C equipment in most of ARI's established product categories.

[2] "Installed value" covers not only the cost of the unitary air conditioner as shipped from the factory but also ductwork, registers and grilles, thermostatic and other controls, electrical wiring, and other components of the system which is engineered and installed by a contractor or dealer.

Turning to more specific equipment, Table VII-23 lists fourteen different types of unitary and applied HVA/C equipment, and indicates their reported 1973 shipments along with various growth rates over the period 1960-74. They are categorized functionally according to each product's major use, although certain products are applicable to both the residential and nonresidential markets. The many product lines which showed negative growth over the past year are indicative of the present condition of the industry, and represent the combined effects of both energy availability problems and a poor housing market.

Over the period 1970-73, the markets for unitary equipment were generally buoyed by two strong years in residential construction. The market for unitary air conditioners particularly showed excellent growth until the poor housing year of 1974 (housing starts off by 33%). The strong showing of heat pumps and electric furnaces since 1970 has been more a function of available residential energy sources. In 1974, electric heating accounted for nearly 50% of all new connections. This compares to only about 20% three years earlier. This penetration by electric heating in new construction came at the expense of nonelectric warm air furnaces and gas- and oil-fired residential boilers.

Applied equipment intended for air distribution and comfort control--induction units, fan coil units, and central station A/C--showed slightly negative growth but not as much as packaged terminal air-conditioners (PTA/C). PTA/C's are heavily involved in hotel and motel construction which had a very poor year in 1974. Electrically-fired centrifugal chillers continued to show solid growth, although the market for reciprocating chillers has been a bigger volume due to their extensive use in low to moderate tonnage applications.

4. Product Trends

That portion of the unitary market directed toward residential construction has shown relatively consistent long-term growth, and indeed is dependent upon new housing starts. On the other hand, the unusually high growth shown by commercial systems during the 1960's was affected by an ever increasing saturation of comfort conditioning systems in new construction. However, since 1970 and continuing through 1974, many of the commercial, or nonresidential markets for unitary and applied equipment and A/C systems have become saturated. As of 1974, ADL estimates the penetration of total comfort HVA/C systems to be as follows:

Sector	Total Comfort HVA/C Systems (percent)
Apartments	90
Commodity-Commercial	56
Prestige-Commercial	95
Institutional	62
Other Nonresidential	65

TABLE VII-22

UNITARY VERSUS APPLIED HVA/C SYSTEMS, COMPARATIVE GROWTH RATES

(percent)

System	Usage	Average Annual Growth Rate 1960-70	1970-74	1974-75
Unitary	Residential	15.6	15.7	1
	Commercial	12.2	10.5	8
	Total	14.0	13.6	4
Applied, or Field-Engineered	Commercial	10.1	2.4	3

SOURCE: Air Conditioning and Refrigeration Institute; Arthur D. Little, Inc., estimates.

TABLE VII-23

DOMESTIC SHIPMENTS OF SELECTED HVA/C EQUIPMENT

Equipment Type	1973 Shipments Thousands of Units	 Value in Millions	Average Annual Growth Rate (Percent) 1960-70	 1970-73	 1973-74
Residential Heating:					
Warm Air Furnace (Nonelectric)	2,168	322	2.5	7.3	-17
Electric Furnaces	378	73	8.0	26.5	6
Gas and Oil Boilers	302	106	0	0	-15
Heat Pumps	119	63	3.5	6.7	15
Residential Cooling:					
Unitary A/C	2,839	1,300	16.8	14.8	-12
Commercial Heating:					
Boilers	3	50	4	4	-20
Commercial Cooling:					
Reciprocating Chillers	10.1	59	7.3	5.3	6
Centrifugal Chillers	3.9	100	10.9	-1.4	10
Absorption Chillers	2.2	27	5.3	-6.5	6
Packaged Terminal A/C	294	76	23.2	24.5	-15
Factory Fabricated Cooling Towers	14.7	42	8.7	0.5	10
Commercial Air Handling Units:					
Room Induction Units	48	3	5.4	-7.0	-6
Fan Coil A/C Units	266	32	6.9	4.5	-4
Central Station A/C Units	51	55	3.2	0.2	1
TOTAL		2,308			

SOURCE: U.S. Department of Commerce; various industry sources; Arthur D. Little, Inc., estimates.

With the exception of commodity-commercial and institutional construction, market penetration is relatively high and should not be expected to leverage growth within the market through 1980. In the case of the 1975 markets, there are indications that the market for HVA/C equipment will not be as depressed as might have been predicted.

While there will always be an established market for applied HVA/C equipment, the better business opportunities (i.e, higher growth rates) will probably exist with unitary equipment. Evidence already exists which indicates that the overall growth in unitary equipment in spite of its dependence upon new housing construction market will exceed that of applied equipment.

Markets for unitary equipment over the period 1975-80 will be affected by improvements in equipment and machine technology which have continually allowed the less expensive, air-cooled condenser equipment to increase in cooling capacity. As a result, packaged air-cooled condensers continue to grow at the expense of water-cooled equipment. The market for water-cooled systems will also be hurt by the increasing number of communities which are placing restrictions on water usage.

Another factor is the recent proliferation of budget-oriented, small commodity-oriented construction, i.e., fast-food stores, which require air conditioning and present a sizable market for unitary equipment. A secondary result of this demand will be the development of more active merchandizing chains, which, in turn, will continue to promote unitary equipment.

In addition to new construction, the addition and alteration market will offer significant opportunities for unitary equipment. Positive factors are the sizable backlog of inefficient systems in operations, the trend towards total comfort systems, and the favorable economics of renovating as opposed to new construction. Unitary equipment will account for much of this market due to its packaging characteristics and ease of installation.

5. Methods of Distribution

The sales of mechanical equipment to the construction industry are affected by many factors, including equipment type, building type, usage, contract type, geographic location, and local competition. The sales channels existing in the building industry for mechanical equipment consist of five major participants: original equipment manufacturer, independent distributor, factory representatives, dealers, and mechanical contractors. The route which components follow to either of the two end-use markets--residential or nonresidential--depends on which of the five major participants handle that particular piece of equipment.

The equipment manufacturer will typically choose to distribute residential equipment through either independent distributors, followed by dealers, mechanical contractors, or a combination of all three. Most commercial HVA/C suppliers employ either distributors or factory representatives, and in addition, augment them with manufacturers' staff in the form of branch offices.

As a general rule, the more technical competence a particular component requires, the more significant the distributor becomes as a sales outlet. Most large distributors enter into exclusive agreements with a manufacturer for a specific product line, where the distributor agrees not to carry competing lines in exchange for an agreed upon marketing territory. The same distributor usually carries other types of products so that he can supply the entire range of HVA/C equipment, and he may or may not have exclusive agreements with these other manufacturers. Where exclusive distributorships are not given, the equipment manufacturer will typically sell to a number of different distributors within a region.

The larger and more sophisticated HVA/C equipment suppliers usually engage in distributorships in which there is an agreement that equipment above a certain size or that is a specialized product will be sold directly by the manufacturer. This agreement is typically made for equipment which is not commonly inventoried or which requires particular technical support. Although no summary data exist, it is believed that those companies which provide the more sophisticated HVA/C equipment realize approximately 50% of their sales from distributors (and factory representatives) and 50% from selling direct through their own branch offices.

Finally, under most situations, distributors and factory representatives do not sell directly to the building owner, although they often come in contact with the owner's architect and engineer by providing the technical support for their products. However, there are situations, called national accounts in which equipment suppliers will approach a large customer directly in hopes of obtaining volume sales. A common example occurs in the marketing of residential construction on a national scale by large developers. Someone such as a furnace manufacturer will secure an exclusive order for his equipment through the developer's home office and deliver the equipment in the field via the distributor, dealer, or mechanical contractor for that particular job. National accounts are also common with large mechanical or general contractors.

6. Quantitative Impact of ASHRAE 90

If widely adopted, ASHRAE 90 could have a significant negative impact on the sales of HVA/C equipment. In fact, energy conservation in general will be the real dark horse of the future for HVA/C equipment. It has long been known within the industry that effects of changing attitudes will have a bigger effect on the size of and type of HVA/C equipment used in new construction than any other single variable, economic or otherwise. Different types of equipment will be affected in different ways; however, the net effect in most cases will be a loss in potential market due to lower system requirements.

For each of the five categories listed in Table VII-23 (residential heating, residential cooling, commercial heating, commercial cooling and commercial air handling equipment), estimates were made of the potential revenues lost to HVA/C equipment suppliers based upon the analysis of the 20 prototypical buildings, the estimated segment of each market which is accounted for by new construction, and the weighted average penetration of central air conditioning anticipated for 1976 by building type.

It should be noted that the large reduction in HVA/C capacities resulting from the application of ASHRAE 90 does not translate directly into equal losses in potential revenues. Table VII-24 shows the decrease in sales value (percentage of initial cost) as a percent decrease in equipment size for several example product lines. This indicates that the market impact of ASHRAE 90 will be somewhat moderate in terms of its actual economic impact due to the higher price per unit of heat/cooling capacity for smaller equipment.

As shown in Table VII-25, ADL estimates that of a total annual market value of approximately $2,308 million, $1,720 million (75%) is intended for new construction and will be affected by ASHRAE 90. Likewise, direct loss in revenues were estimated to be $185 million, representing 11% of the affected market and 8% of the total market for HVA/C equipment as defined.

7. Qualitative Impact of ASHRAE 90

ASHRAE 90 will result in more efficient equipment over the long term. Until now, equipment which has been produced in response to the first-cost sensitivity of the industry will come under closer scrutiny, and the lesser efficient products will all but disappear over the near term. A review of the efficiencies and COP's listed in the standard does not indicate a hardship for well established suppliers who are capable of improving their product lines over the schedule allowed for in the standard.

We foresee that ASHRAE 90 will encourage the short-term increase in cost per unit of heating/cooling capacity as manufacturers begin to pass off the cost of product improvement directly to the customer. Also manufacturers will be required to develop and publish detailed performance data, and in doing so, will be encouraged to improve equipment so as to remain competitive.

HVA/C equipment suppliers will be able to slightly offset the estimated potential market loss of $185 million, due to the following reasons:

- ASHRAE 90 will encourage a trend toward applied equipment as opposed to unitary equipment, although the trend toward unitary systems may not be entirely reversed by ASHRAE 90. The value to the supplier of applied equipment is greater than of unitary equipment.

TABLE VII-24

EFFECT OF DECREASED EQUIPMENT CAPACITY ON EQUIPMENT PRICE FOR SELECTED HVA/C PRODUCT LINES

(percent)

Product	Reduction in Equipment Capacity			
	-20%	-30%	-40%	-50%
No. 2 oil-or gas-fired boilers	11	19	25	33
Centrifugal and reciprocating electric chillers	13	19	32	40
Upflow heating furnace with chilled water coil	16	19	21	38
Split system air conditioners, air cooled	23	27	42	43
Fan coil units with cabinets	8	13	18	20

SOURCE: Arthur D. Little, Inc., estimates.

TABLE VII-25

ECONOMIC IMPACT OF ASHRAE 90 ON HVA/C EQUIPMENT INDUSTRY

(million of dollars)

Category	Approximate Market Size	New Construction Only	Loss in Revenue (percent)	Los
Residential Heating	564	460	-15	
Residential Cooling	1,300	910	- 6	
Commercial Heating	50	40	-24	
Commercial Cooling	304	240	-19	
Commercial AHU	90	70	-20	
	2,308	1,720		

SOURCE: Arthur D. Little, Inc., estimates.

TABLE VII-25

C IMPACT OF ASHRAE 90 ON HVA/C EQUIPMENT INDUSTRY

(million of dollars)

Approximate Market Size	New Construction Only	Loss in Revenue (percent)	Loss in Potential Market
564	460	-15	-60
1,300	910	- 6	-55
50	40	-24	-10
304	240	-19	-46
90	70	-20	-14
2,308	1,720		-185

e, Inc., estimates.

- Manufacturers will begin to concentrate on product lines which will have positive business opportunities due to the "energy conservation ethic." Examples are variable air-volume equipment, heat pumps, and heat wheels.

- Suppliers will develop new ways to "repackage" those lines most susceptible to a negative impact. For example, the use of multiple boilers as a replacement for one (or two) larger units results in a higher per unit sales price.

- Once the significant savings are reported on new construction, building owners will be open to suggestions on replacing older less efficient equipment with improved models, and manufacturers will begin to develop the replacement market.

An example of this last issue might be the commercial boiler industry. Like other HVA/C manufacturers, their market has been predominately centered around new construction. With the coming of the energy crisis, there have been significant opportunities to replace World War II-vintage boilers in buildings which were designed for solid fuel and which are now gas or oil-fired with newer more efficient equipment.

The impact on the existing distribution system will be greatest on the wholesalers who, like the manufacturers, will be handling less value, and thus possibly having to increase their costs of handling. Dealers and installers will not be affected providing their costs are passed through to the building owner. The impact on the smaller commodity-oriented auxiliary equipment will be negligible and in many cases may be positive.

Finally, from a viewpoint of energy conservation, the trend towards unitary equipment is somewhat unfortunate. Such equipment is typically less energy efficient than field-engineered systems. While it appears that energy conservation design requirements like ASHRAE 90 will somewhat encourage a trend back to field-engineered components, it will probably not be sufficient to entirely reverse the trend toward unitary equipment.

J. IMPACT ON HVA/C CONTROLS MANUFACTURERS

1. Product Definition

The HVA/C control industry includes those devices made to control central plant and unitary heating, ventilating, and air conditioning equipment in both residential and nonresidential construction, generally by monitoring temperatures. Within the industry, there are two major sectors--residential and commercial--each of which presents different types of markets and control requirements to market participants.

In the residential market, control manufacutrers sell only equipment--mostly room temperature control--for installation within mobile homes, single-family residences, and some low-rise apartments. In the commercial market, control manufacturers act as both equipment suppliers and contractors selling total installation. Market areas include all nonresidential construction and a certain number of multi-family units (estimated to be less than 10%) which utilize central plant HVA/C.

2. Industry Characterization

The annual markets for residential and nonresidential HVA/C controls and services is extremely concentrated with three companies controling approximately 65-70% of the business. ADL estimates the top five companies account for 80-85% of annual revenues. The market positions of the larger participants have been established over many years and are somewhat immune to most competitive pressures from new entrants and secondary suppliers. However, competition between the major suppliers is extremely keen for three reasons:

1) In the commercial sector, controls manufacturers are typically contractors dealing in a high risk, low return business;

2) Successful market entrance is dependent upon high technology compared to the rest of the HVA/C industry; and

3) Business success is heavily dependent upon a broad coverage of the field (e.g., many field offices), and as such, is not too unlike many large construction contractors.

Another major difference between residential and commercial controls suppliers is that nonresidential market participants in general are in a better position to capitalize on recently developed business opportunities than are residential market participants. Two examples of these new opportunities are building automation controls and various fire, safety, and life support devices, which for years, have not been aggressively pursued by most HVA/C control suppliers.

3. Market Analysis

In 1961, the Federal Trade Commission charged the major manufacturers with collusion in determining product prices, and the long-term result has been the absence of a formal trade association which serves to collect and publish total industry sales. Thus, at best, industry sales of HVA/C controls can only be estimated. ADL's figures are based upon discussions with selected industry representatives, and should be recognized as such.

In 1974, it is estimated that $550 million was spent on HVA/C controls and installation services, or about 6% of the total expenditures for HVA/C systems (approximately $5 billion). Of the total, $250 million were for residential markets, and represent controls only with no installation. Of this, 60 to 65% were shipped directly to OEM customers who included the controls within their equipment. The remaining 35 to 40% was shipped to trade distributors (e.g., wholesalers). The market for new construction lies in both of these sectors, but is probably concentrated more within OEM installers.

The remaining $300 million market is for equipment and services in commercial construction, where only about $30 million (10%) is thought to be direct sales to OEM equipment suppliers. The remaining $270 million is sold directly to construction. In general, only about 20% of the total commercial market is accounted for in retrofit applications compared to 40-45% in the residential market.

4. Impact of ASHRAE 90

As in other construction industries investigated, the impact of ASHRAE 90 will be greater on the commercial sector than on the residential sector. The impact on the control indsutry will be positive by creating additional demand for building controls.

Quantitative estimates of the impact of ASHRAE 90 are summarized in Table VII-26. Of the total controls market, an estimated $410 million (74%) could potentially be affected by ASHRAE 90. Additional market demand was estimated to be $21 million, which is derived mostly from the commercial sector.

A majority of single-family residential construction is still single zone, requiring one thermostatic control per unit. With few exceptions, the demand for space temperature controls in new residential construction will not increase significantly due to ASHRAE 90, although there could be an increase in the number of thermostats per housing start of approximately 20%, based upon the number of stories (i.e., zones) per unit. The residential market should remain basically an electric control market, whose equipment requirements will not change due to ASHRAE 90, other than to have different range settings. No cost of installation impact is expected assuming standard industry installation procedures.

In the commercial sector, the additional market for new controls was estimated based upon the prototypical building types analyzed. In addition, ASHRAE 90 will bring about other industry impacts in commercial construction, including some increased demand for terminal controls (i.e., return air controller) will be supplied with units, and probably factory mounted.

In the case of electric and electronic controls for unitary equipment (i.e., roof mounted units and unit ventilators), controls may or may not be factory mounted, but essentially will retain the same costs assuming standard industry installation procedures. In those field applications where additional temperature controls are required, new controls might more often be pneumatic, rather than electric, due to their longer term lower operating cost. However, the present estimated market mix of pneumatic controls to electric/electronic controls will change little, say from 20/80 now to 25/75.

TABLE VII - 26

IMPACT OF ASHRAE 90 ON HVA/C CONTROL MARKETS

(millions of dollars)

	Residential	Commercial	Total
Estimated Annual Markets	250	300	550
OEM Market	150	30	
Trade Market	100	270	
Annual Market Accounted for by New Construction	140	270	410
OEM Market	90	27	
Trade Market	50	243	
Total Market Impact Due to ASHRAE 90	+6	+15	+21

SOURCE: Arthur D. Little, Inc., estimates.

Design engineers have long known that significant savings are obtainable through better HVA/C system controls, and as the project size increases design engineers are more likely to investigate additional control sophistication (i.e., automation) based upon proven economic criteria. The indirect markets developed aggressively in this manner will probably overshadow those markets created directly by ASHRAE 90, but might not have come about without some impetus from energy conservation legisltation. For example, building automation systems cost on the order of $.30 to $.40 per square foot versus $.08 to $.10 per square foot to comply with ASHRAE 90.

Finally, controls manufacturers will probably support ASHRAE 90, although the impact on the controls industry is anything but a windfall business. It can be argued that adequate controls have been provided on buildings since 1950, but that they have been used improperly. Secondary reactions on the part of the controls industry will include a more aggressive business development strategy for existing construction. The industry has long been supported by new construction, and as such, has not necessarily capitalized on retrofit opportunities, which will become more prevalent as the "energy conservation ethic" expands. These indirect markets may well exceed the specific control opportunities presented by such requirements as the substitution of variable-air-volume equipment for more inefficient terminal equipment, additional OEM control requirements for proven energy efficient equipment such as heat pumps, and the extended use of economizer cycles for pojrects as small as 12 tons of cooling capacity.

K. COMPARATIVE IMPACTS

Table VII-27 summarizes the ten specific industry sectors analyzed for economic impact due to ASHRAE 90. The total annual market affected by ASHRAE 90, and the maximum potential impact of ASHRAE 90 are shown. In some cases, the figures have been rounded for comparative purposes.

Total markets for those industry sectors investigated for direct economic impacts amount to slightly over $9.4 billion annually, of which approximately $5.6 billion, or 60%, could potentially be affected by ASHRAE 90. Thus, while the extent to which individual industry sectors will be affected by the standard varies widely (from 14 to 92%), on average, over half of their total annual revenues could potentially be influenced by ASHRAE 90. In comparison to the anticipated $168 billion construction industry in 1976, it appears that the direct impact attributable to the standard is limited to but a few specific industry sectors, most of which show a positive, or at worst, a minor negative impact.

In general, the adoption of ASHRAE 90 will create opportunities for suppliers of commodity building materials at the expense of reducing those markets for general building equipment and HVA/C systems. If adopted in its entirety, ASHRAE 90 would cause a significant additional market for building insulation, particularly rigid board due to its applications in nonresidential construction. At the same time, the

TABLE VII-27

SUMMARY OF ECONOMIC IMPACTS DUE TO ASHRAE 90

	Total Annual Market ($MM)	Market Affected by ASHRAE 90 ($MM)	Market Affected by ASHRAE 90 (%)	Maximum Potential Impact by ASHRAE 90 ($MM)	Percent of Total Market (%)
Building Materials Suppliers:					
Insulation:	1,000	595	(60)	+179	+18
• Batt	470	270	(57)	+ 4[illegible]	+10
• Rigid Board	460	280	(61)	+128	+28
• Loose Fill	70	45	(64)	+ 6	+ 9
Siding Materials	1,000	850	(85)	+ 12	+ 1
Flat Glass	1,247	146	(12)	+ 7	+ 1
Windows	903	720	(80)	- 19	- 2
Building Equipment Manufacturers:					
Electric Lamps	1,177	176	(15)	- 16	- 1
Lighting Fixtures	1,450	830	(57)	-175	-12
Gas and Electric Meters	173	159	(92)	+ 3	+ 2
Hot Water Heaters	289	117	(40)	+ 4	+ 3
HVA/C Systems Manufacturers:					
HVA/C Equipment	2,308	1,720	(75)	-135	- 8
HVA/C Controls	550	410	(74)	+ 21	+ 4

SOURCE: Arthur D. Little, Inc., estimates.

TABLE VII-27

SUMMARY OF ECONOMIC IMPACTS DUE TO ASHRAE 90

l Annual Market ($MM)	Market Affected by ASHRAE 90 ($MM)	(%)	Maximum Potential Impact by ASHRAE 90 ($MM)	Percent of Total Market (%)	Percent of Affected Market (%)
1,000	595	(60)	+179	+18	+30
470	270	(57)	+ 45	+10	+17
460	280	(61)	+128	+28	+46
70	45	(64)	+ 6	+ 9	+13
1,000	850	(85)	+ 12	+ 1	+ 1
1,247	146	(12)	+ 7	+ 1	+ 5
903	720	(80)	- 19	- 2	- 3
1,177	176	(15)	- 16	- 1	- 9
1,450	830	(57)	-175	-12	-21
173	159	(92)	+ 3	+ 2	+ 2
289	117	(40)	+ 4	+ 3	+ 3
2,308	1,720	(75)	-135	- 8	-11
550	410	(74)	+ 21	+ 4	+ 5

estimates.

standard would induce a major negative impact on the HVA/C equipment and lighting fixtures markets. The remaining market sectors will receive only a minimal impact due to ASHRAE 90 in comparison to either their total annual or affected markets.

The building materials markets investigated represented about $3.4 billion of annual business as compared to $6.0 billion for general building and HVA/C equipment manufacturers, yet the former category could realize as much as $176 million in new markets versus a potential loss of $348 million by equipment suppliers. In particular, HVA/C equipment suppliers appear to be in the most vulnerable position, with 75% of their identified markets affected by ASHRAE 90.

The single largest market created by the standard is in rigid board insulation, however, the size of the affected market is considerably diluted, and as such, a market participant would have to be narrowly focused in on new commercial construction in order to capitalize on the opportunity, a situation which is not typical of insulation suppliers.

The single largest negative economic impact will be on the markets for HVA/C components, which unlike commodity materials suppliers, are heavily oriented toward new construction. There are few, if any, large secondary markets available to HVA/C equipment manufacturers capable of offsetting a major loss in their potential sales volume due to conservation-oriented design. While HVA/C equipment suppliers will be able to somewhat moderate this negative impact to a large extent, they will nevertheless suffer from any type of effective energy conservation legislation, be it ASHRAE 90 or some similar design standard.

Most of those companies associated with the construction industry in some manner have previously experienced sudden and significant impact on their markets and still survived. The situation investigated here is comparative to those sudden annual downturns resulting from annual residential cyclicality and safety- or fire-oriented code modifications. These industry sectors will again be able to adapt to changes in their markets due to energy conservation influences without direct assistance from Federal and/or State agencies.

Finally, as discussed elsewhere, the success of ASHRAE 90 in achieving energy conservation and the resulting economic impact on the construction industry is highly dependent on the degree of implementation and enforcement of this standard by appropriate agencies. More than any other single factor, these institutional factors will dictate and control the document's eventual impact. However, the estimates of economic impact given here could be greatly affected by nearer-term variations in construction activity. If, for example, housing starts were to recover at a faster rate and achieve higher levels than the 1.5 million units presently forecast for 1976, total demand for fenestration products, with or without ASHRAE 90, would increase proportionately. Thus, any over- or under-estimations of construction activity would result in similar over- or under-estimations of absolute economic impact, although the relative percentage impact is likely to remain about the same.

CHAPTER VIII

IMPACT OF ASHRAE 90 ON SELECTED INDUSTRY PARTICIPANTS

A. INTRODUCTION

ASHRAE 90 will affect certain participant groups within the construction sector, the major effects being more along the lines of "institutional impacts." The standard would appear to have an interesting, and sometimes surprising, effect on three groups in particular: residential builders and developers, architectural and engineering (A/E) design firms, and code authorities. The impacts on each of these is discussed in detail within this chapter, with special emphasis on the A/E design firms.

B. IMPACT ON RESIDENTIAL BUILDERS AND DEVELOPERS

1. Industry Characterization

The U.S. housing builders and developers produce slightly over 3% of our annual gross national product in the form of single-family houses and apartments (both low- and high-rise) and representing a broad diversity of styles, sizes, and levels of sophistication. The actual number of home builders is not known since there are thousands of builders some of whom build one house per year, some of whom build thousands. It is estimated that there are approximately 50,000 builders of which perhaps 200 build over 1,000 units per year, 500 build between 100 and 1,000 units, and the rest build fewer than 100 per year. All of these operators have different structures, modes of operation, and specialties, and generalizing on them is difficult.

The housing industry is characterized by its lack of concentration and its cost sensitivity. It, like most sectors of the construction industry, is locally-oriented and extremely market sensitive. The business is extremely cyclical. In 1974, 1.35 million units were built of which one-third were apartments of more than one unit, and two-thirds were single-family. Two years before, the total was almost double this, or 2.4 million units of which 47% were multi-family. Two years prior to that, in 1970, 1.5 million units were built with approximately 40% being multi-family.

This cyclicality has been apparent for decades; it is caused principally by the varying cost and availability of mortgage money rather than by the basic demand for housing units. This cyclicality forces the companies in the business to maintain maximum debt equity ratios, to keep a very thin staff, and to avoid commitment of fixed capital in plant and equipment. The companies therefore must be flexible in structure so they can accommodate both the big years and the very lean years. This perhaps explains why housing companies are cost sensitive and respond to the immediate market opportunities rather than making permanent commitments to the industry.

With reference to Table VIII-1, the sections below will describe the three generic types of home builders in order to develop a perspective of how they might be impacted by the implementation of ASHRAE 90.

2. Giant Developer

The giant developers, defined as those developers who build more than 1,000 residential units per year, currently number less than 200 and account for barely 10% of total new units built. However, it is important to understand their modus operandi because they will increase in importance. They are more sophisticated and rational than their competition, and their methods of operation are emulated by many smaller builders. Most of the giant developers build low-rise apartments and multi-family as well as single-family houses. They are sophisticated, well-run companies and not the stereotype opportunistic carpenter/builder. Many of these firms are publicly-held companies with significant financial resources and technical skills. In many ways the giant builder is like a manufacturing firm; it buys land, inventories it, adds value to it, and sells it. While the working capital required for this value adding is very high, the critical problems arise in selecting sites, changing zoning, and in determining the type of house to be built. The actual construction is the simplest portion of the job, and one to which they devote the least attention.

Many giant builders use the single-family unit as a production item to generate cash flow rather than earnings. In this way, various combinations of single-family and multi-family units make an attractive financial package to the large developers.

The giant builder is totally market oriented; and because he has so much money tied up in land and site improvements, it is crucial to put the "right" house on the land and turn it over rapidly. He does not, therefore, want to experiment with new styles, new designs, and new production methods. He wishes to keep his capital cost low, and provide maximum flexibility in the product so that he can meet a multitude of needs of the buyer with regard to house color, shape, style, etc.

The builder will be inclined to use energy conservation schemes on his units for one of three principal reasons:

1) On a model house to build traffic, i.e., as a promotional gimmick to draw people to his house even if he does not in fact sell the energy conservation scheme.

2) As an option. The giant builder sells a house like an automobile salesman sells a car by trying to add extras to a sale since the profit on the extras is higher than on the house itself. If there is a saleable reason for energy

TABLE VIII-1

COMPARISON OF RESIDENTIAL DEVELOPERS AND BUILDERS

	GIANT DEVELOPER	MEDIUM DEVELOPER	S
Estimated Number of Builders:	200	500	
Typical Annual Volume (Units):	>1,000	100 to 1,000	
Percent of Annual Units Built:	10%	20%	
Characteristics:	Sophisticated, rational; high front end capital for land development; interested in both SF and MF	Emulates methods of giant builders; less staff for planning, marketing; less financial resources; tend to be either SF or MF	Skills va custom ho doing tra cost unit
"Role" of the House:	Generates cash flow	Profit	
Emphasis Placed Upon:	Site selection, zoning changes, determining type of unit, rapid turnover	Reducing package cost of homes; financial interest in MF	Cost redu
Attitudes Toward Energy Conservation:	High; seen as good budiness opportunity	Fair for SF; Good for MF; but acceptability and proof will be significant issue	Poor; div group; ma pragmatic

SOURCE: Arthur D. Little, Inc.

TABLE VIII-1

COMPARISON OF RESIDENTIAL DEVELOPERS AND BUILDERS

GIANT DEVELOPER	MEDIUM DEVELOPER	SMALL BUILDER
200	500	40,000
>1,000	100 to 1,000	<100
10%	20%	70%
Sophisticated, rational; high front end capital for land development; interested in both SF and MF	Emulates methods of giant builders; less staff for planning, marketing; less financial resources; tend to be either SF or MF	Skills vary; some doing custom homes, but most doing traditional low-cost units
Generates cash flow	Profit	Profit
Site selection, zoning changes, determining type of unit, rapid turnover	Reducing package cost of homes; financial interest in MF	Cost reduction
High; seen as good budiness opportunity	Fair for SF; Good for MF; but acceptability and proof will be significant issue	Poor; diversity within group; many are too pragmatic

c.

conservation, and a proven system, the giant builder will offer such extras but only as an option since he does not want to risk losing a sale. However, in order for the giant builder to use energy conservation schemes as an option it must be a financially attractive system for which insurance and warranties are available. He is obviously risk adverse and will not experiment for the sake of experimentation.

3) When required by law.

3. Medium Developer

The medium tract developers are those who typically build between 100 and 1,000 units per year. Most of these firms have characteristics which make them only fair candidates for conservation systems promotion. They tend to operate within one region, thus making them more sensitive to regional economic vagaries; they tend to have less staff in the planning, marketing, and technical functions; they have far less financial resources in technology and marketing; they tend to be followers rather than leaders and are more cost sensitive than the giant builders. They also tend to do more of the actual construction themselves and are more concerned with the profit on construction than the total project. While the giant builders often produce both single-family "for sale" units and investment multi-family units, medium-sized builders tend to prefer only one or the other.

The decision making process in multi-family housing is quite different from single-family; basically, it is a financial deal. Table VIII-2 shows the type of analysis usually used in developing an apartment complex. The economic value is determined by market forces. The net income (rent income less fixed costs) is capitalized at a rate generally higher than mortgage rates to develop the economic value. The developer then attempts to "mortgage out" the project by getting a mortgage equal to the economic value. He then attempts to build the unit for less than the mortgage so he keeps the difference. So with virtually no equity, he owns the building and makes a large profit in construction.

There is obviously a reason to use energy conservation schemes if the cost of installing such devices lowers utility costs in a greater proportion than the capitalization rate. But understanding this relationship is sophisticated and the promoter must be sure of his costs and technology. Acceptability and proof will be the significant issues, and since the medium-sized builder is not too sophisticated, he probably will follow custom rather than innovate.

4. Small Builders

In the housing industry, there are a number of very small builders who average perhaps eight units per year and are limited to the single-family market. Because there are so many of them (ADL estimates 40,000) it is difficult to generalize on them or their motives. They collectively

TABLE VIII-2

FINANCIAL ANALYSIS OF A 100-UNIT GARDEN APARTMENT

(Thousands of Dollars per Year)

Income Source:	
Five 4-Bedroom @ $350 per Month	21
Twenty 3-Bedroom @ $300 per Month	72
Fifty 2-Bedroom @ $250 per Month	150
Twenty 1-Bedroom @ $200 per Month	48
Five Efficiencies @ $150 per Month	9
Gross Rent	300
Vacancy Allowance 5%	15
Total	285
Operating Expense	25
Utilities	30
Local Taxes	60
Net Income	170
Economic Value (Capitalized @ 10%)	1,700
Cost of Project	
Land	100
Construction	1,400
Financing	100
Total	1,600
Initial Cash Return to Builder if mortgaged at economic value	100

represent approximately 70% of new starts in a typical year. A few of them build custom houses where they are more cost insensitive, but most of them build more traditional low-cost homes. Their skills vary from builder to builder; some might be sophisticated, some might be genius, but most are pragmatic. Because of their diversity, they will represent a difficult hurdle for implementation of ASHRAE 90 since they are so small, so scattered, so uninformed, and so pragmatic. Even legislation reagrding energy conservation standards will be ineffective in reaching all of these builders very rapidly.

5. Impact of ASHRAE 90

For the following reasons, ADL believes that the successful implementation of ASHRAE 90 will have an insignificant impact on residential home builders. They may have to spend a small amount of time interpreting the document, designing construction approaches to comply with the standard, and accept the fact that construction costs may go up or down a few percent, but provided they are all meeting the same standards the impact on their marketability, on market share, or on financial performance should be negligible.

Most residential builders do not have design or engineering groups to interpret the standard. A few that do, mostly giant builders, can meet the requirements simply at an insignificant design cost. Those that do not have these capabilities probably will meet the requirements on specific recommendations furnished them by their local Homebuilders Association or building material suppliers. The fraternity of builders in a regional area is close, and they will easily exchange ideas and develop effective ways of meeting the requirements.

In the analysis referred to earlier in this report, the cost penalties required by the implementation of ASHRAE 90 on the prototypical houses were shown to be negligible. In point of fact, there is a broad diversity in housing designs. Some of these are like stucco in California, block in Florida, wood frame in New England. Therefore, the cost impact in implementing ASHRAE 90 may vary from region to region and, more importantly, within a region, but on balance the cost impact still should be minimal. Further, since only approximately half the selling price of a single-family home is made up of direct field and labor costs, the opportunity to lower costs is as great in the indirect as in the direct costs, particularly since the job costs vary from job to job and project to project. A 2% change plus or minus in the direct costs will be relatively small compared to the other changes in land costs, costs imposed by the ecology considerations, and the cost of capital. These will be far more significant to the builder economics than will the relatively simple changes suggested by ASHRAE 90.

As stated before, the builders are typically very heavily market-oriented. They attempt to produce what they perceive the buyer to want. There is a long-standing belief in the building industry that the women usually make the final choice on a house in regard to its appearance, location and style, while the husband is concerned about the monthly costs that a given house requires. The women in the mass market tend to select a house with the most eye appeal, color, visible kitchen equipment, and so forth. The functions that are hidden or whose benefit is not visible are very hard to sell. This has been demonstrated for painted-for-life sidings, insulation, stronger studs and the like. The same will be true for the benefits of ASHRAE 90 to most of the consuming market. The more sophisticated purchasers may ask if this house is efficient from an energy point of view. If the builder tells the buyer the house meets or exceeds standards, the home owner will have to take the builder's word for it. In situations where those come up there is no way to prove the house is thermally efficient, which leads to concerns in enforcing the standard and which are discussed later in this chapter.

The wise builders seeking profit opportunities on sale of their houses may well use the energy crisis as a sales tool to sell extras, but these for the most part will have to be visible. For example, even if the house meets ASHRAE 90 standards, he may offer the consumer double glazing as an extra when indeed the insulation (which cannot be seen) may be marginal or poorly installed. His sales ability, therefore, may make profit opportunities from the energy crisis, and the standard could positively impact this if, through its promotion, the consumer were made to be more energy conscious.

The only condition under which the enactment and implementation of ASHRAE 90 could negatively impact some builders would be if it were not equitably enforced. If one builder in a local market met ASHRAE 90 and another did not because of ignorance or deceit, the builder who did not meet it could either offer the same house at a slightly lower price or could add more visible extras. While the percent difference would be miniscule, it would be a slight advantage. Since insulation is installed and almost immediately covered up, the unscrupulous builder can skimp on the insulation requirements. He can use thinner insulation than required. More likely, he can install it improperly so as not to make if fit tightly, omitting it altogether from small stud areas under windows, or not sealing it properly. It is the quality of installation as much as the quality of insulation that will produce energy savings; unfortunately, the quality feature is invisible very shortly after it is installed. This will create a tremendous difficulty for the inspectors, if not the builders. If the code officials act arbitrarily--as require a builder to leave a sheet rock off the walls until it has been inspected--this could hold up the fast flow of labor if the inspector were not immediately available when required. This sort of bureaucratic interference with the housing construction procedure could have a major impact on the financial performance of one builder relative to the other.

In summary, it appears that the few percent, plus or minus, that ASHRAE 90 imposes on the homebuilding industry will have insignificant effect if it is uniformly administered. In fact, it might create profit opportunities for the builder by raising the consumer awareness of the energy situation and provide him with the opportunity to increase his profit per sale.

C. IMPACT ON THE ARCHITECTURAL/ENGINEERING DESIGN PROFESSION

1. Industry Characterization

The actual application of ASHRAE 90 will be done during building design, and will involve both architects and design engineers, or as the industry refers to them, the design profession. Historically, the approach to designing single-family homes and certain apartment buildings has been different than that for the larger residential and commercial buildings. The differences are, for the most part, a function of the size and complexity of the building and its systems, with the residential system being an order of magnitude simpler.

Residential design work is generally considered to be single-family and low-density housing (up to four units) and low-rise multi-family dwellings, either apartments or condominiums. The architect is the key individual, and on most small jobs, engineering support for such items as HVA/C and domestic hot water are provided by either the architect himself, local contractors, or equipment suppliers. While a small percentage (ADL estimates 5%) of single-family homes are designed by independent registered architects or small partnerships, the majority of new housing starts are undertaken from prepared plans, or from designs from within the developer's or custom homebuilder's staff. Likewise, packaged heating and cooling systems are easily selected by either the staff, contractors, or manufacturer's representatives.

In contrast, the nonresidential design profession encompasses most high-rise and some low-rise multi-family structures, commercial and institutional establishments, and various industrial plants. Commercial buildings are designed either by consulting architectural and/or design design engineering firms, internal design departments within major companies, construction firms with design capabilities (i.e, "design-construct" or "turnkey"), preengineered building manufacturers, or in some cases, consortiums of contractors and HVA/C equipment manufacturers. In all cases, the mechanical and electrical systems as shown on the working drawings of the project are more complex than their residential counterparts.

Of the several alternative methods of designing commercial projects, only one--consulting architectural and/or design engineering firms--derives its entire income on billings for design services. There are basically four types of "design" organizations:

- Architectural/engineering/planning firms (A/E/P);
- Architectural/engineering firms (A/E);
- Architectural firms, and
- Consulting engineering firms.

A/E/P and A/E firms have the capability of doing both the architectural and engineering design while an architectural firm typically subcontracts a consulting engineering firm for such assistance. In addition to the above, some A/E/P and A/E firms are in fact "design constructors" in that they not only have design capabilities but construction capabilities as well. This is not very common, however, and the number of ordinary design firms usually far surpasses the number of design/construct firms.

In terms of influence, design engineering firms or integrated firms with engineering capabilities are critical to the selection of HVA/C equipment. Their comparative influence by building type might be summarized according to the following schedule, recognizing that their influence in certain types of projects have historically been offset by the type of owner requesting the work.

Strong Influence:

- Multi-Family High-Rise
- Office Buildings, Prestige
- Schools
- Hospitals
- Government Buildings

Moderate Influence:

- Shopping Centers
- Office Buildings, Commodity
- Motels

Occasional Influence:

- Multi-Family, Low-Rise
- Industrial Plants

There is little correlation between the type or size of the project building being designed and the size of the design firm doing the work. However, historical precedent within the profession has dictated that certain design firms are more widely recognized for doing certain types of projects than are others. While all firms which have been practicing over some longer period of time have typically designed a wide variety of building types, many of their projects might fall into but a few classifications (i.e., health care facilities, sports facilities, laboratories, pulp and paper mills, etc.). By definition of the architect/engineer relationship, the architect plays only a minor role in the actual design and selection of HVA/C equipment, the process most acutely affected by the adoption of ASHRAE 90.

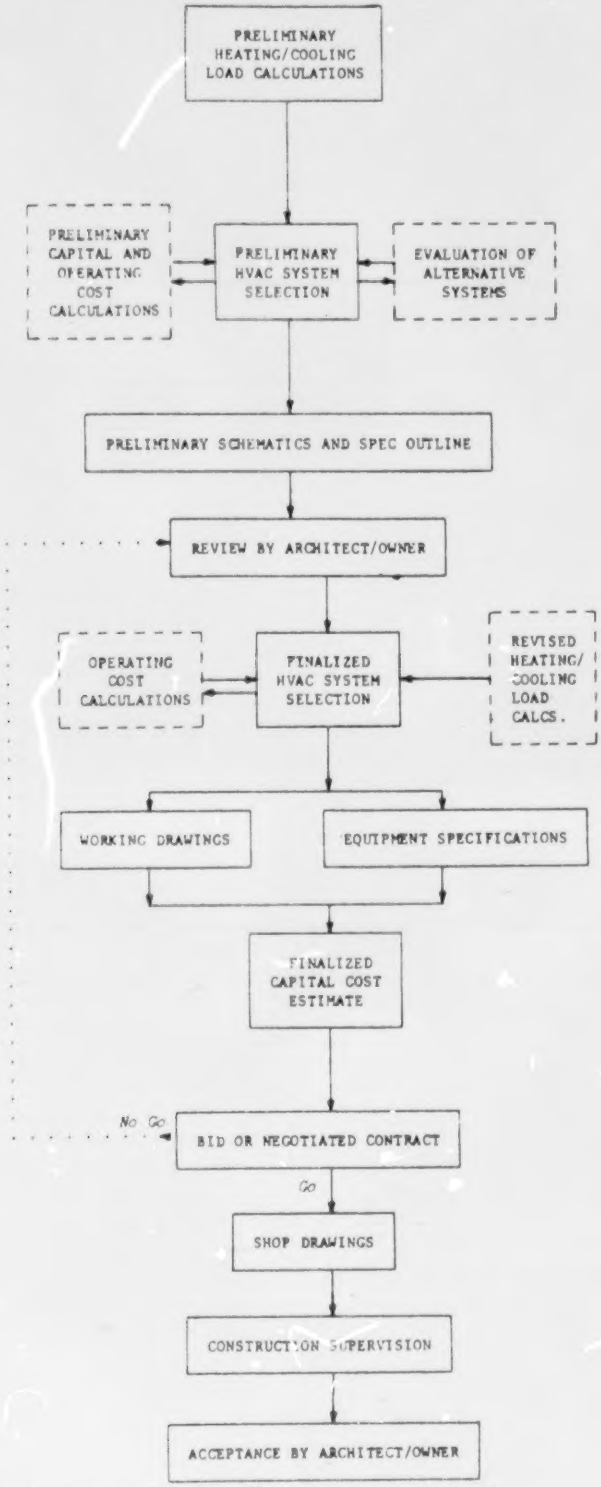
2. The Design Process

The design procedure by which HVA/C systems are selected for large residential and commercial buildings varies with building type but might be summarized by the flow chart of Figure VIII-1. (This procedure is shortened considerably in designing systems for residential construction.) To the engineer, the introduction of ASHRAE 90 to buildings implies an adjunct to conventional design procedure, and a chronological review of Figure VIII-1 will identify those steps for which ASHRAE 90 has critical implications.

FIGURE VII-1

FIGU

DESIGN OF HVA/C SYSTEMS FOR BUILDINGS


PRELIMINARY HEATING/COOLING LOAD CALCULATIONS
PRELIMINARY CAPITAL AND OPERATING COST CALCULATIONS
PRELIMINARY HVAC SYSTEM SELECTION
EVALUATION OF ALTERNATIVE SYSTEMS
PRELIMINARY SCHEMATICS AND SPEC OUTLINE
REVIEW BY ARCHITECT/OWNER
OPERATING COST CALCULATIONS
FINALIZED HVAC SYSTEM SELECTION
REVISED HEATING/ COOLING LOAD CALCS.
WORKING DRAWINGS
EQUIPMENT SPECIFICATIONS
FINALIZED CAPITAL COST ESTIMATE
No Go
BID OR NEGOTIATED CONTRACT
Go
SHOP DRAWINGS
CONSTRUCTION SUPERVISION
ACCEPTANCE BY ARCHITECT/OWNER

SOURCE: Arthur D. Little, Inc.

The HVA/C design process commences with a preliminary engineering estimate of the heating and cooling loads of the building which are usually based upon some form of architectural schematic. These loads are estimated using unit factors (i.e., 150 square feet per ton of cooling) which have been derived for that particular building type and geographical location. Using such estimates, a preliminary HVA/C system is selected based upon the functional, capital cost, and operating cost considerations of each of several alternative systems.

Next a preliminary schematic of the proposed system and an outline of accompanying specifications are compiled prior to a review of the system, the project architect and client owner.

Following this, the engineer attempts to finalize the HVA/C system design by first revising the heating and cooling loads to account for those architectural considerations which have been developed since the preliminary calculations were made. At this point, some consideration is usually given toward identifying the operating costs (i.e., energy consumption) of the particular system selected. Under the design procedures previously practiced by the industry, little, if any, further effort will be expended to more accurately identify these operating costs unless the client or job specifically requires it.

Once the system has been finalized, the design firm must produce a set of working drawings accompanied by a set of equipment specifications which describes the configuration and performance requirements of the HVA/C system respectively.

The final steps in the design process are rather routine. A finalized estimate of the cost of the mechanical systems is drawn up and submitted to the architect/owner. This cost is often used as a basis in determining if the bid (or negotiated contract) should be let. If the subsequent bids are too high, the engineer may wish to re-evaluate or re-estimate the mechanical system; if not, then the bid is accepted and that contract is let. The design firm's last responsibilities typically are the verification of shop drawings and the field administration of actual construction to insure that it conforms to the plans and specifications. Lastly, the firm accepts the job on behalf of the owner.

3. Impact of ASHRAE 90 on the Design Process

The responsibility of applying ASHRAE 90 to any project lies mainly upon the design mechanical and electrical engineers, particularly the former. The effect upon the architectural services to be provided will be diluted once preliminary studies have determined such items as exterior skin, percent and type of fenestration, building configuration, etc. Other design disciplines which contribute to a project will be negligibly affected and include sitework, interior design, civil and structural engineering.

In the residential sector, the design calculations for heating and cooling loads are relatively simple and have been reduced in most cases to single, short-form methods based upon single-zone equipment. Examples are ARI's Standard 230 and NESCA's J-1 method. ADL foresees a small effort in applying the standard prescriptive/performance approach of ASHRAE 90 (Sections 4 through 9) to residential construction. In fact, the manner in which the standard is written (including certain exemptions) should encourage rapid familiarity of the standard on the part of residential designers. For the small architect, homebuilder, or developer, the initial use of ASHRAE 90 should present the most difficulty, with subsequent applications much easier. The major short-term problem will be interpretation of the standard, which could easily be alleviated through seminars conducted by either local professional societies or by the Homebuilders Association.

By comparison, the methods used in sizing commercial HVA/C equipment are much more complex due to the greater number of assumptions and variables which must be considered concerning load contribution and system configuration.

Referring again to Figure VIII-1, not all tasks in the design process will be affected by the adoption of ASHRAE 90. Basically, those tasks following the finalized HVA/C system selection will occur as they presently do. Finalizing capital cost estimates, reviewing bids (or negotiating contracts), verifying shop drawing, and monitoring construction progress should not be affected by the standard. The preparation of some working drawings and the drafting of equipment specifications will become only slightly more time consuming. It, therefore, appears that the adoption of ASHRAE 90. will tend to load-up the "front end" of the design process. If the engineer is to comply to ASHRAE 90, basic information, particularly on the detailed performance of certain materials and HVA/C equipment is required during the preliminary load calculations so that their applicability may be initially evaluated. Ideally, design professionals will probably compile noteboooks or short-form design tables relating the performance as a function of location, building type, building size, etc., over time. This will tend to shorten the time required to undertake preliminary design.

ASHRAE 90 will also result in more HVA/C design calculations, further technical and economic evaluation of alternative systems, additional internal and external meetings of the design team, more interaction with code authorities on standard interpretation, and subsequent verification that the finalized project complies with the standard.

For the client/owner or design professional who chooses to customize his design under the aegis of Section 10 or 11 of ASHRAE 90, the preliminary mechanical engineering phase will become even more important, require a larger effort, and demand more professional design fees than under Sections 4 through 9. The designer will be concerned with methods to recycle energy above and beyond those stipulated in the standard prescriptive/performance approach, and will be required to prepare detailed statements of energy usage for each alternate he considers.

If Section 10 is applied as it was intended, then this will almost assuredly make electronic computation mandatory rather than short-form hand computation because of the detail that must be considered in the analysis. Experience has shown that such detailed engineering analyses and economic computations have been undertaken on too few projects, and then, typically only on large or complex buildings where a significant payback in improved construction was thought to exist.

ASHRAE 90 will generally encourage the use of electronic computation on all projects, and once the favorable trade-off on building first cost has been established, the expanded use of such techniques on large projects to determine the optimum building design, rather than one that just meets the standard. This may be further encouraged by rising construction costs and potential shortages of energy, and will lead owners of new facilities to investigate presently available items such as automated control of HVA/C systems, automatic load shedding when predetermined demands have been reached, etc.

The larger engineering offices with access to and experience in the use of computers will be more inclined to use the Section 10 approach in order to select among alternatives for the project. Those smaller offices who do not have experience in or ready access to computers are expected to follow the prescriptive/performance approach of Sections 4 through 9.

Finally, ADL believes that the above effect on the front-end of the design process need not affect the project schedule *providing* the engineer is brought on board at the very first instance and commences his effort at the same time the architect begins his schematics. If ASHRAE 90 is made legally binding, and *if* enforcement of its provisions takes the form of mandatory review and approval by an understaffed code authority, then construction delays could be substantial in addition to requiring additional time to prepare engineering information for use by the regulatory agency.

4. Industry Fee Structure

There are several methods of payment for architectural/engineering design services. For typical design and construction administration services, billings have predominantly been based upon a percent of the total project cost, or in the case of HVA/C design, the mechanical systems cost. Alternatives to this include fixed fee (lump sum), or for smaller jobs, a straight multiplier of the payroll. In addition, other types of services such as trouble-shooting, field tests, detailed measurement of existing buildings, expert witness, and economic feasibility studies are normally considered as being separate work efforts with separate compensation. For most design firms, billings from these types of services are generally secondary to billings for normal design services.

Fee schedules based on historical data are commonly developed by national and/or state chapters of professional societies.[1] On a percentage fee basis, actual billings will be a function of the following variables:

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[1] For example, the American Institute of Architects, the National Society of Professional Engineers, the American Consulting Engineers Council, etc.

- Type of building, e.g., degree of design complication;
- New construction or alteration;
- Size of project, and
- Scope of responsibilities, e.g., singular or interprofessional work.

As an example of recommended fees, Figure VIII-2 shows a fee curve published by an engineering society. Such curves do not actually set the actual fees, but act as guidelines.

Traditionally, the prime contract position in the design of buildings has been with the architect. The architect, in turn, has traditionally entered into a subcontract with a mechanical/electrical design engineering firm. In those cases where the architect's remuneration has been on a percentage of the construction cost basis, this method of remuneration has been passed through to the subcontracting mechanical/electrical engineer. Resulting mechanical/electric engineering fees are generally in the range of three-quarters of the percentage the architect receives multiplied by the subcontract cost for the mechanical and electrical systems.

Given the above, it was necessary to estimate the total cost for design and construction surveillance services so that the economic impact of ASHRAE 90 on fees could be estimated. Industry billings are reported by two sources based upon periodic surveys.[2] Unfortunately, the data is not presented in sufficient detail so as to determine which billings were actually for design of new construction (versus nonbuilding, alterations, and other services) nor to eliminate the possibility of double-counting, i.e., the fees passed directly through by the architectural firm to the engineering firm, and which would be reported as revenues by both companies.

Using an alternative approach, ADL estimated the total potential billings which could be realized by the design profession in 1976, based upon the assumptions of construction activity presented in Chapter VI. These are summarized in Table VIII-3, and have been adjusted to allow for those design services provided by residential developers, pre-engineered buildings manufacturers, client/owner staffs, and other sources. The estimates include those services provided by design-build consortiums on turnkey projects. Similarly, they have been weighted to account for the distribution in project sizes and design complexity.

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[2] Annually by Engineering News Record, and once every five years by the Department of Commerce.

FIGURE VIII-2

MINIMUM RECOMMENDED FEES FOR MECHANICAL WORK

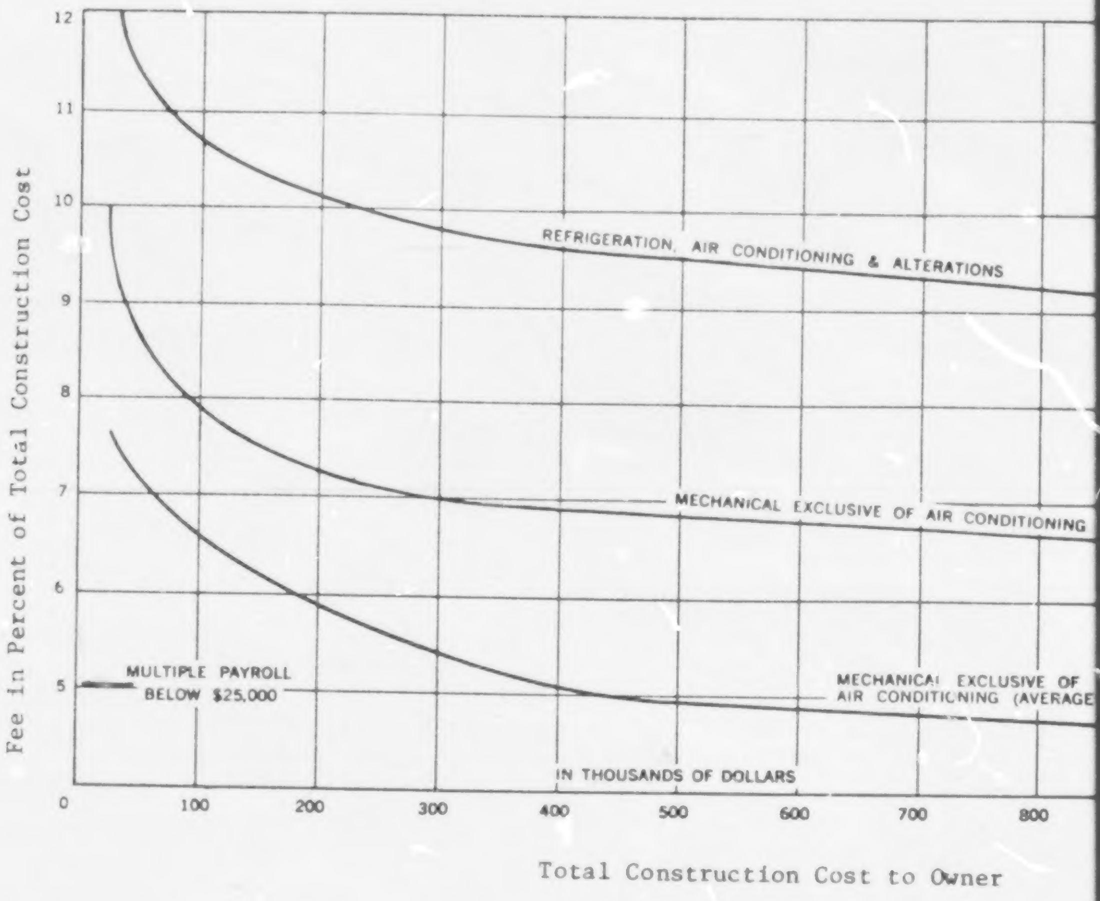

FIGURE VIII-2

MINIMUM RECOMMENDED FEES FOR MECHANICAL WORK

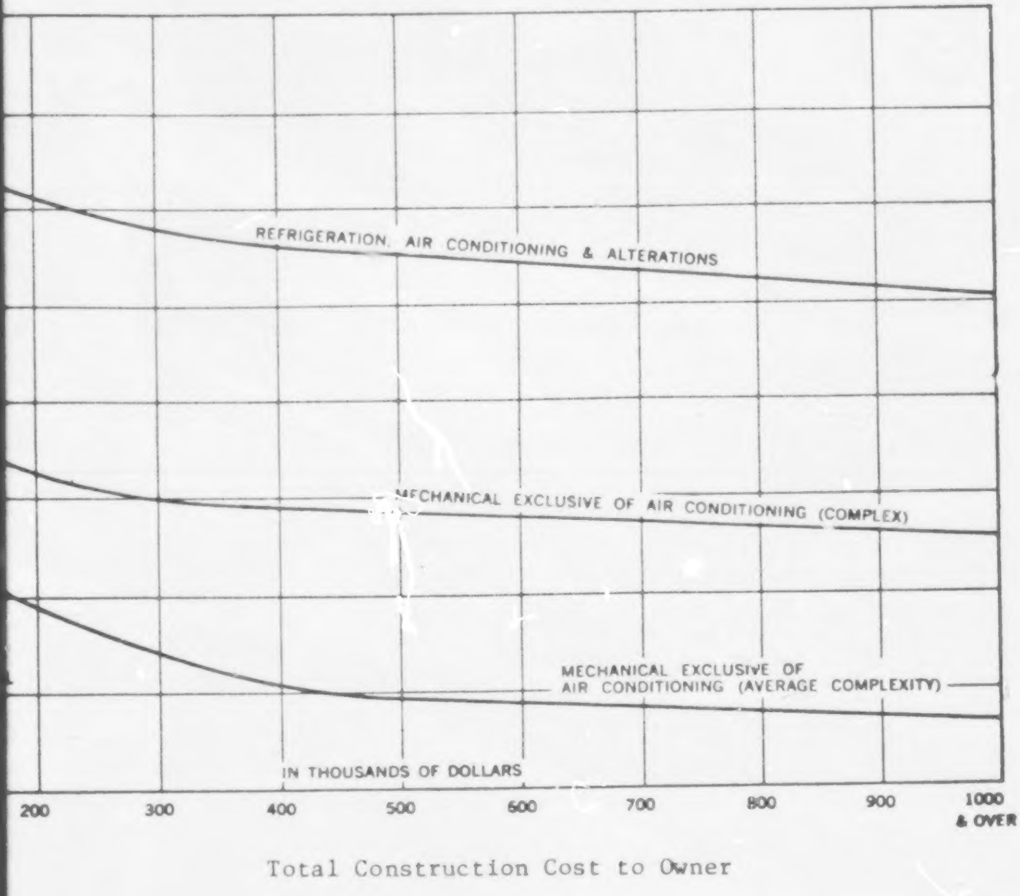

TABLE VIII-3

ESTIMATED ANNUAL BILLINGS[1] AVAILABLE TO THE DESIGN INDUSTRY FOR RESIDENTIAL AND COMMERCIAL CONSTRUCTION, 1976

(Millions of Dollars)

Sector	Percent Architect Designed	Percent Engineer Designed	Estimated Annual Buildings[2] Architect Only	Estimated Annual Buildings[2] Mechanical/Electrical Engineer
ESIDENTIAL				
Single-Family	5	--	245	--
Low-Density	5	--	10	--
Low-Rise Apartments	15	5	110	5
High-Rise Apartments	60	60	110	20
Sub-Total			475	25
ON-HOUSEKEEPING RESIDENTIAL	30	30	20	5
	Architect's Fee (% of Total Project)	Mechanical/Electrical Engineer's Fee (% of M/E Subcontract)		
ON-RESIDENTIAL				
Office Buildings/Banks	8.9	5.8	260	70
Retail Establishments	8.7	6.6	345	100
Industrial	6.3	4.8	270	80
Educational	9.0	5.8	360	95
Hospitals/Health Care	10.0	5.8	230	60
Miscellaneous	8.9	5.9	280	75
Sub-Total			1,745	480
TOTAL			2,240	510

Excludes expenses which are estimated to be 15% additional.

Billings available to design profession only, excludes all in-house design capabilities.

SOURCE: Arthur D. Little, Inc., estimates.

ADL estimates the billings which will be accounted for by design architects in private practice due to residential construction only to be $385 million in 1976. This is predominately in single-family construction, where architect-designed custom-built units account for only 5% of total construction (but 7% value).

In high-rise multi-family construction, architectural bills are estimated to be $130 million and mechanical/electrical services (some of which will be realized by A/E and A/E/P firms) to be $25 million. Non-housekeeping residential, i.e., hotels, motels, will require an estimated $20 million of design architectural services and $5 million of mechanical/electrical services. As in all residential construction, the total potential billings would be much greater were it not for the design of such buildings by staffs captive to owner companies.

In the commercial sector, the potential billings available to design architectural only and mechanical/electrical engineering firms were estimated to be $1,745 million and $480 million, respectively. However, design services are provided by several parties, with only a portion of these actually occurring as billings to design firms. An estimated 32% of new construction value is accounted for by A/E designed projects put out to bid and an additional 12% by A/E designed projects under negotiated contracts. Design construction teams account for 37%. Pre-engineered buildings account for 7% and other various sources for the remaining 9%. The trend in recent years has been away from the A/E designed projects and toward design-build jobs, with pre-engineered and other design sources holding about equal.

Adding both residential and nonresidential billings, ADL estimates that $2,750 million of architectural/engineering services would be affected by ASHRAE 90. Of this, $510 million worth of mechanical/electrical services alone would be affected.

In order to put this in perspective, total industry billings are estimated to be $7.4 billion in 1976. This accounts for all firms, regardless of size, and all types of services. Thus, we estimate that approximately 40% of total design industry billings could potentially be affected by ASHRAE 90.

5. Impact of ASHRAE 90 on Fee Structure

The increased effort and responsibility on behalf of the mechanical engineer, and to a lesser extent the architect and electrical engineer, will not be without its cost, particularly in commercial projects. As the mechanical engineer becomes more important to the design process, it follows that his fees will increase over their present levels. Even a rudimentary analysis by the engineer to determine if a building is in compliance with ASHRAE 90 would require additional funding on behalf of the client/owner. In an area (HVA/C design) in which the professional fees historically have not been easily increased even for such basic exercises of comparing the operating economics of alternative systems, a minimum increase in fees over those incurred by the design of conventional HVA/C systems would not have been well received in the past. However, we anticipate the adoption of ASHRAE 90 may lower some of the institutional barriers against increased design fees based upon reasons which will be discussed later.

The present structure of mechanical design fees is extremely stringent requiring that, in practice, very little of the available funds be spent on basic engineering since most of the fee is required for detailed design, preparation of drawings and specifications, review of shop drawings, and field inspection during the construction period. Thus it has been usual that mechanical systems be initially selected by the "seat of the pants" of the principal in the engineering firm. Involvements with architects during schematic design were frequently limited to roughing out the amount of space required for mechanical equipment and establishing the approximate allocation for vertical and horizontal chases for distribution systems. The space requirements were established at this stage by rules of thumb based on past experience and usually accomplished after the fact of the preparation of the architect's schematic design with an unquestioning acceptance of the architect's building orientation, amount of glass, proposed insulation (if any) in exterior walls, shading, etc.

This established procedure does not lend itself to the realities of the adoption of ASHRAE 90, which in its simplest form, requires a larger effort for a subsequently smaller mechanical system. Therefore, any fee based on a percentage would serve to recover only part of the design effort involved in designing a better system.

This has been reinforced by engineering offices which have been designing in general accordance with the systems analysis procedures outlined in Section 10 over the past few years, where it became apparent that present fee structures are grossly inadequate to include the cost of engineering and detailed economic analyses. Accordingly, contracts for building design will have to be varied to permit payment to the engineer, preferably on a cost reimbursement or lump sum basis, for the basic engineering phase leading to system selection. Other alternative fee arrangements based on effort, rather than on project cost could be equally acceptable. At the very least, an overhaul of the presently recommended fee structure based on percent cost is called for by ASHRAE 90.

The question of how much an increase in design fees can be expected is critical. Estimates were made based upon both Figure VIII-1, and upon the allocation of design time between each of the tasks in the design process. With reference to various NSPE publications on the determination of partial payments of consulting engineer fees, the estimated breakdown of such fees is as follows:

Preliminary Load, Calculations, and System Selection	15
Finalized Design and Design Development	20
Preparation of Working Drawings and Equipment Specifications (Construction Documents)	40
Bidding or Negotiation	5
Verification of Shop Drawings, Construction Administration	20
	100%

Based upon discussions with various design firms, ADL estimated that under the worst possible case, the effort allowed for preliminary system selection and finalized design development would increase by 40% under the prescriptive/performance approach of ASHRAE 90. It was also estimated that the preparation of the construction documents would increase by 10%. Based on the above breakdown, this results in an increase in overall design effort of 18%, and the application of those approaches dictated by Sections 10 or 11, could add an additional 20% to this. This limited data suggests that the implementation of ASHRAE 90 on a given project would result in slightly less than a 20% increase in design fees under the present fee structure.

This seems reasonable. As a check, this estimate was compared to those previously prepared for NBS by several design firms which analyzed the effect of NBS's original energy conservation design guidelines on several actual projects. The estimates are in concurrence with those.

Based on this, ADL estimates ASHRAE 90 could result in as much as $92 million in additional fees for design mechanical/electrical engineering firms.

A similar increase in architectural fees would occur. While no accurate method of estimating what additional services would be required in support of ASHRAE 90 was available, the architectural effort was assumed to be an additional 30% of that required of his engineers, in addition to the premium fees realized by passing through the increased engineering/fees to the client/owner. This would amount to approximately $60 million in 1976.

The A/E's ability to collect for such services is strongly dependent upon the health of the construction industry at the time. If work is scarce, additional services might be undertaken at lower, or no increase in fees simply to "fill up the shop." If work is plentiful, the A/E will realize all fees due him.

6. Qualitative Impact of ASHRAE 90 on Design Firms

As Sections 10 and 11 of ASHRAE 90 gain in usage, certain A/E firms (and/or some individuals) within the construction industry will become synonymous with them over the near term. Initially, these firms will probably be those which have historically from time to time either deviated from conventional design of mechanical systems toward feasibility and/or energy studies, or which have undertaken projects which encompass more complex mechanical systems. Examples of more complex systems worthy of systems analysis approach might include the design of HVA/C and process systems associated with hospital "clean rooms" and research laboratories among others. Examples of nondepletable energy source studies are solar and wind powered systems.

As for the other firms, there will always be a difference in professional competence between both individuals and individual design firms. Like any other profession, certain participants have better reputations than many of their counterparts, and the introduction of systems analysis (Section 10) and alternative energy (Section 11) approaches to buildings will be achieved more readily (and with greater success) if the design of that particular project is entrusted to those engineers noted for their inventiveness and capacity to design unique or complex mechanical systems.

Furthermore, as unique energy conservation design schemes become more familiar (and acceptable) to the entire construction sector, the expertise required to design such systems will spread throughout the design profession and become less oriented toward those firms which initially became associated with the concept. The more design firms that become familiar with the schemes and concepts, the faster the integration of such systems into projects of all types will take place.

Since there appears to be no correlation between the size of engineering firms and the design of those project types which are believed to be best suited for unique approaches to energy conservation design engineers will be pressured to adopt new techniques as a profession rather than as members of a particular engineering firm. Fortunately, established channels already exist within the industry for the dispersion of energy conservation ideas. These channels, such as ASHRAE, are already geared toward individual engineers and are independent of firm size and particular employer.

Finally, from a professional standpoint, perhaps the most significant impact of ASHRAE 90 is that the design engineer will become a more important and integral member of the design team. This will not happen without some responsibilities. The engineer will be required to become expert on a wider variety of detail, such as the performance of various types of equipment, energy demands of various types of distribution systems, together with the basis on which they are evaluated. He will be much more involved in providing assurance to the client that equipment efficiencies are as specified. Section 10 may lead to the installation of more varied types of equipment in order to reduce the size of traditional equipment, and in some cases, it is anticipated that the owner will hire mechanical/electrical engineers directly to prepare basic reports on environmental systems prior to permitting the architect to proceed beyond schematic design.

7. Economic Impact on Those Prototypical Buildings Investigated

Finally, the economic impact of additional design services on each of the five prototypical buildings was investigated. Table VIII-4 shows the estimated cost to the building owner of additional design services using an 18% premium on the cost of the mechanical electrical services in addition to expenses. The cost of additional design effort is shown to be between $0.09 and $0.36 per square foot of project floor area. In order to gain a perspective on this, Table VIII-5 compares these additional design costs to the annual savings realized in energy costs. With the exception of the single-family residence, the straight payback of design services due to energy cost savings was found to be less than one year, and less than six months in most cases. From this it can be concluded that the premium fees required for design services are extremely cost effective, and in addition to a minimal, if any, increase in first cost, ASHRAE 90 will have a favorable impact on building economics.

D. IMPACT ON CODE AUTHORITIES

1. Introduction

A building code is a compilation of rules regulating the construction, alteration, demolition of buildings, the materials, equipment and appurtenances installed therein and the occupancy thereof. It is a legal document of the governmental subdivision which established it by ordinance or statute. It has the force of law and violations are subject to legal penalties.

The purpose of a code simply stated is to protect people, the public from harm, and its basic principle is that the establishment of minimum standards to protect the health, safety and welfare of the public is within the police power of the state. The limits of police power have never been clearly defined, and consequently building codes are flexible and have expanded to cover every imaginable situation and condition in connection with buildings and their occupancy.

2. Code Types

About 8,000 codes are current in the United States today. Most states--and every community, as a creation of the state--has codes relating to building construction. These are typically a Building Code, a Mechanical Code (frequently incorporated within the Building Code), a Plumbing Code, and an Electrical Code. There is one national code of sorts, in that the provisions of the 1970 Occupational Health and Safety

TABLE VIII-4

IMPACT OF ASHRAE 90 ON THE COST OF DESIGN SERVICES FOR PROTOTYPICAL BUILDING INVESTIGATIONS[1]

Building Type	Total Project Cost	Mechanical/Electrical Cost	Estimated Conventional Design Costs[2]		Additional Design Costs Require to Meet ASHRAE 90[3]	
			Architect[4]	Mechanical/Electrical	Architect[5]	Mechanical/Electrical
Single Family	33,500	7,000	4,700	---	400	---
Multi-Family Low Rise	351,000	80,700	36,800	5,600	600	1,000
Office Building	1,280,000	435,200	116,500	21,300	2,400	3,800
Retail Store	550,000	160,000	55,500	9,900	1,100	1,800
School	1,200,000	384,000	109,200	19,200	2,200	3,500

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[1] Includes all fees for design and construction.

[2] Surveillance and associated expenses.

[3] Assumes the standard prescriptive/performance approach.

[4] Exclusive of M/E services.

SOURCE: Arthur D. Little, Inc., estimates, based on accepted industry fee practices.

TABLE VIII-4

IMPACT OF ASHRAE 90 ON THE COST OF DESIGN SERVICES FOR PROTOTYPICAL BUILDING INVESTIGATIONS[1]

chanical/Electrical Cost	Estimated Conventional Design Costs[2]		Additional Design Costs Required to Meet ASHRAE 90[3]			Additional Design Service ($/Sq. Ft.)
	Architect[4]	Mechanical/Electrical	Architect[5]	Mechanical/Electrical	Total	
7,000	4,700	---	400	---	400	0.24
80,700	36,800	5,600	600	1,000	1,600	0.09
435,200	116,500	21,300	2,400	3,800	6,200	0.16
160,000	55,500	9,900	1,100	1,800	2,900	0.09
384,000	109,200	19,200	2,200	3,500	5,700	0.15

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s, based on accepted industry fee practices.

TABLE VIII-5

COMPARISON OF THE COST OF ADDITIONAL DESIGN SERVICES TO ANNUAL ENERGY SAVINGS

(Dollars/Sq. Ft.)

Building Type	Annual Energy Savings	Additional Design Services	Straight Payback
Single-Ramily Residence	0.07	0.24	2.9 Yrs.
Low-Rise Apartment	0.31	0.09	3.4 Mo.
Office Building	0.40	0.16	2.5 Mo.
Retail Store	0.68	0.09	7.6 Mo.
School	0.70	0.15	4.6 Mo.

SOURCE: Arthur D. Little, Inc., estimates.

Act (OSHA) apply to places of work nationally, but OSHA is the only example of such broad applicability.

Historically, each community has written its own codes, hence, their notorious variability. Plumbing and electrical codes tend to be more uniform than building codes, being generally variations of the ASME's National Plumbing Code and the NFPA's National Electrical Code, and being frequently of statewide, rather than local, adoption.

Today, the locally written code is giving way to locally adopted codes based on one of the four proprietary "model" codes, or more commonly, to state codes. The Federal government, viewing code variation as a major deterrent to industrialized building, and therefore, adding unnecessarily to building cost, is pushing communities, or preferably states, to adopt one of the model codes with as little modification as possible. Data on the source breakdown of codes today are hard to find. the 1973 International City Management Association[3] sampling of 919 cities (basis of sampling unspecified), found:

73% use a model code, perhaps modified
13% use a state-written code
12% use a locally-written code
2% use no code at all.

There are four model codes in use today:

1) National Building Code (NBC), first promulgated in 1905, this is the only model originated by the insurance industry rather than by a grouping of code enforcement officials. It is alleged to be primarily a fire code, with comparatively little detail on structural, etc., requirements, and is used mainly in the North and the East.

2) Uniform Building Code (UBC), first issued in 1972, and in general use in the Mountain and Pacific states.

3) Southern Building Code (SBC), issued in 1945, and used throughout the South.

4) Basic Building Code (BBC), issued in 1950, is the ascendant model code in the Middle West and the Northeast.

Codes are revised at any time, by local ordinance. Architectural and Engineering News (April 1967) stated that of the approximately 12,000 jurisdictions then regulating construction, 3,500 were using a model code, but 75% of those had modified it.

The model codes are revised on three- to five-year intervals, by the technical staff (or the AIA in the case of the NBC) and by vote of the professional membership in the other three cases. Anyone can originate a request for code change. The request, with relevant data, is reviewed by the code body's technical staff and placed on the annual meeting agenda. This is the "code change" procedure by which the actual model code is rewritten. The change then automatically applies in those communities which have adopted the model code without reference to year, though not necessarily (only at the enforcement officials' discretion) to those which adopted a particular code issue.[4]

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[3] F. T. Ventre, Social Control of Technological Innovation: The Regulation of Building Construction (MIT Ph.D. thesis, 1973, unpublished).

3. Technical Standards and Other Regulations

The codes necessarily incorporate by reference a great body of technical standards. Like the codes themselves, these standards may or may not be adopted by a particular year of issue.

Standards originate from three basic groups, having somewhat different interests:

1) Industry groups, or industry supported laboratories, whose interest is primarily in defining terms, describing tests, and categorizing products so that meaningful comparisons can be made, dependable specifications written and orderly competition maintained. A claim sometimes heard is that standards may be written down to include the least member of the sponsoring group. (Examples: ASTM, ANSI, Department of Commerce Commercial Standards, Federal Specifications, lumber grading rules.)

2) Insurance groups, whose interest is in safety, or at any rate the preservation of insured values. (Examples: UL, NFPA, Factory Mutual.)

3) Professional groups, interested in design methods and performance testing. (Examples: ASHRAE, ASME, APHA, AWWA.)

In addition, regulations other than the building code are applicable to building construction. These are primarily but not exclusively rules of a state agency or department with power to formulate and enforce regulations within limits prescribed by law. Most common among these are health and sanitation requirements of the State Board of Health, fire safety and fire prevention regulations of the State Fire Marshal, safety rules for construction operations.

Zoning regulations are generally entirely separate from the building code but sometimes enforced by the chief building official. These are concerned with location of industrial, commercial, residential buildings, street setbacks, parks, recreational and other aspects of orderly urban growth.

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[4] Not only can a community adopt one or another model code, but it can also adopt a particular year of issue, and fail to adopt a subsequent revision.

Federal Agency requirements are applicable to federally owned construction and to some Federal aid programs. The Federal government seldom participates in code development but does influence code requirements to some extent by their own acceptance standards and specifications. Some Federal specifications are adopted as reference standards in building codes.

4. Current and Future Trends

Each code is the result of a compromise between the various forces and influences operating on the particular jurisdiction emanating the code. The strength of various lobbies can alter the outcome of a piece of code legislation and the typical result is a conservative compromise that is competent in its engineering and safety requirements but unimaginative, and frequently uneconomic in its implementation. Apart from the recent and important influences of Federal and State Governments, we have traditionally seen the major influence of the municipal building inspector, local engineers and architects, union and nonunion contractors, competing building manufacturers and independent consultants and testing laboratories. Many of these categories are represented on a national level by various state and professional associations such as the American Concrete Institute, the Cast Iron Soil Pipe Institute, the Society for the Plastics Industry, the National Association of Plumbing, Heating and Cooling Contractors and the various unions. In the face of increasing government pressures the influence of unions and building inspectors is modifying, that of architects and engineers is waning and that of building materials manufacturers becoming more aggressive or defensive depending on which side of the fence they presently sit.

The unions, never strong in the traditionally open shop residential sector, are likely to put up a stronger fight against changes in the nonresidential codes as they have a vested interest to safeguard. They will be suppported in this by the relatively conservative consulting engineers.

It is likely, however, that some degree of regionality will come to the code picture in the next few years with the more active participation of the Federal government through agencies such as the Department of Housing and Urban Development, the National Bureau of Standards, and the National Conference of States on Building Codes and Standards (NCSBCS). The fragmented situation is confusing to the designer, expressive to the building owner and inflationary to the economy.

Finally, a recent and growing trend has been toward performance codes whereby, in theory, any material can be used so long as it meets the standard of performance set up for it. This trend has had an additional stimulus from the energy crisis, causing governments to provide design requirements and criteria that will result in the efficient utilization of energy.

6. Implications of ASHRAE 90 for Code Authorities

Despite the degree of rationality which is coming slowly to the code picture and the increasing number of states that have energy conservation laws, ASHRAE 90 must face two critical issues before it can be an effective standard and achieve its purpose of national energy conservation in building design. These two central issues are implementation and enforcement.

Since Operation Breakthrough, many efforts by state and federal authorities to cajole and encourage code conformity and standarization have failed or have been only partially successful. While it is true that the Federal government can exercise influence on building standards through a combination of moral suasion and positive incentives, linked to FHA, VA, and other housing and building programs and are brought about by the construction of government buildings under the umbrella of the GSA, it has been ADL's experience that this influence is fairly limited in its total effect on the uniform standards and improved quality of construction in the U.S. It would thus not be surprising that a standard dealing with an abstract objective--for example, achieving national energy self-sufficiency--will not succeed where more concrete concerns with such visible problems as consumer and third-party health and safety have failed to motivate institutional change and code effectiveness. It is ADL's judgment that those institutional barriers that have so far prohibited the adoption of a model code on a fairly universal basis, or even the acceptance of a state code on a more limited basis, will continue to create barriers for the implementation of ASHRAE 90 or allow it to be implemented only in a cannibalized form.

A reading of the ASHRAE 90 Standard indicates that the document only asks for design inspection and not for field inspection. Even if states implement part or all of the standard, there is still the crucial question of effective field enforcemnt. Experience with state codes has shown that, because of resource limitations, enforcement of state codes is weak. Substantial financial resources are the main requirement, together with the commitment by state code officials to use these monies for the recruitment, effective training and deployment of sufficient manpower to do an adequate job of enforcement. But how much manpower is sufficient and how much money would be required, especially for the residential sector, remains an unanswered question.

Although some states are obviously doing an adequate job of enforcement of their codes, it is ADL's opinion that any enforcement of ASHRAE 90 will almost certainly be in a patchwork fashion and thus the estimates of economic impact must necessarily be regarded as expressions of maximum impact, assuming full implementation and enforcement.

It must also be concluded that any energy conservation standard cannot simply be imposed from above but will only be achieved gradually by a combination of innovative measures. The necessity for uniform standards has not yet impressed the majority to demand enabling legislation and what certainly is going to be required is considerably more education aimed at the energy consumer to make him aware of the cost/benefit advantage to his own pocketbook of energy conservation so that he can accept and endorse the concept and then support it with his voice.

Finally, it is the potential weapon of financial incentives or penalties. It has become evident to us through other studies related to the investigation of alternative sources of energy that the financial institutions are generally very conservative in appraising property for mortgage loans and rarely take into account the ability of the mortgagee to carry rapidly escalating energy operating costs alongside his housing costs. Conversely, financial institutions generally appraise a property on the basis of market value, and not construction value, and historically have tended to penalize structures that are designed in order to conserve energy and reduce operating costs but which were more expensive as a result. A combination of financial incentives, probably built into the utility rate structure, and tied to the implementation of energy conserving construction methods, and of penalties aimed at the energy user to achieve the same results must be actively considered if energy conservation in building design is truly to be achieved.

CHAPTER IX

IMPACT OF ASHRAE 90 ON BUILDING HABITABILITY

A. INTRODUCTION

Habitability will be discussed here primarily in terms of the effects of increased indoor air pollution, or contamination, and reduced humidity control on health. This analysis is based upon a review of the published literature, unpublished indoor air quality conferences, and recent indoor air quality research for ASHRAE.

B. INDOOR AIR POLLUTION

Indoor air contamination has been of interest to the technical community for many years, and several studies have resulted in a general understanding of the subject, including the following:

Types of Pollutants

- Particulates
- Gases

Pollution Sources

- Outdoor air (varies with ventilation and infiltration rates, air inlet locations, etc.)

- Indoor sources (cooking, smoking, heating, aerosol spraying, vacuum cleaning, office copying, etc.)

Pollution Removal

- Pollutant reaction with or deposition on structure or furnishings.

- Air cleaning equipment (particulate and gas sorption filters, electrostatic precipitators, air washers, etc.)

- Exhaust ventilation and exfiltration

1. Types and Sources of Indoor Air Pollutants

Indoor air pollutants consist of those present outdoors plus those generated indoors. The major outdoor pollutants are the subject of national ambient air quality standards--particulates, sulfur dioxide (SO_2), carbon monoxide (CO), photochemical oxidants, hydrocarbons, and nitrogen dioxide (NO_2). Pollutants generated indoors in industrial environments are numerous and have been studied extensively, but pollutants generated inside residential and commercial spaces such as offices, stores, schools, etc., have received almost no attention.

Odors are not generally a health hazard but are an important pollutant. More than half of the complaints received by pollution control agencies concern odor.

The health hazard of particulate air pollutants depends largely on particle size. Large particles deposit in the upper respiratory tract and are less hazardous than those which can penetrate to the lungs. The latter are called "respirable" particles and are defined by the American Conference of Governmental Industrial Hygienists (1974) as those which pass through a size selector with the following characteristics:

Aerodynamic Diameter (unit density sphere) (μm)	Particles Passing Through Size Selector (%)
2.0	90
2.5	75
3.5	50
5.0	25
10.0	0

Large particles can cause acute upper respiratory effects, but respirable particles can deposit in the lungs and remain for long periods of time, resulting in greater potential for chronic health problems.

Two sources of indoor air pollution are ventilation with outside air and infiltration. These sources will become less important under ASHRAE 90, and indoor pollution sources will become more important.

Current information on indoor sources of air pollution is limited largely to the nature of the sources. Pollutant species, concentration, and emission periods are almost unknown; however, indoor air pollution sources that have recently been studied are as follows:

- Smoking (Bridge and Corn, 1972; Elliott and Rowe, 1973; and Hinds and First, 1975).

- Cooking--CO and NO_2 from Gas Stoves, and Particulates (Schaefer, et al., 1972; Hunt, 1973; DeWerth and Himmel, 1974; Elkins, et al., 1974; Cote, et al., 1974; Sarofim, et al., 1975; and Himmel and DeWerth, 1975).

- Vacuum Cleaning and Dusting (Lefcoe and Inculet, 1971; Thompson, 1972; Annis and Annis, 1973; and Hunt, 1973).

- Aerosol Can Spraying[1] (Cote, et al., 1974).
- Water spraying in air conditioners and humidifers.[2] (Schulze, et al., 1967; Grieble, et al., 1970; Banaszak, et al., 1970; and Rosenzweig, 1970).

Sources of indoor contaminants which have been studied in less detail are:

- Space and hot water heaters--combustion products (Benson, et al., 1972; and Henderson, et al., 1973).
- Copying machines (ozone).
- Garages (Benson, et al., 1972).
- Electrostatic precipitators--ozone (Mueller, et al., 1973).
- Paints (solvents).
- Polymeric furnishings (monomers and plasticizers).
- Construction materials (e.g., fiberglass or asbestos from ventilation ducts).
- Insecticides (Leary, et al., 1974).

This list of sources suggests that generation of nonindustrial indoor air pollutants will be greatest in the home.

2. Removal of Indoor Air Pollution

Removal of indoor air pollution is currently practiced largely by exhaust ventilation and exfiltration, but again these techniques will become less important under ASHRAE 90.

Air cleaning techniques are convenient to discuss in terms of coarse and fine particulates and reactive and less reactive gases, with particulate removal being by far the most common in both residential and nonresidential HVA/C systems.

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[1] Aerosol products are especially important in that a wide variety of toxic and inert materials, such as hair sprays and deodorants are converted into respirable particulates. Freon and other gaseous propellants are also of concern.

[2] Micro-organisms have been observed to grow in the water and be sprayed into the air.

Coarse particulates (larger than 2 μm diameter) can be removed by sedimentation, electrostatic precipitators, filters, and aqueous sprays. For example, pollen is large and has been found to be removed rather effectively by air conditioners and air cleaners (Benson, et al., 1972). On the other hand, fine particulates (smaller than 2 μm diameter) pass through many types of air cleaning equipment and settle very slowly in air.

Reactive gases, such as sulfur dioxide and ozone, can be removed by reaction with furnishings, structure, aqueous sprays, and adsorbent filters (Benson, et al., 1972; Mueller, et al., 1973; and Sabersky, et al., 1973). Less reactive gases, such as carbon monoxide and hydrocarbons, are more difficult to remove.

Major air cleaning techniques are as follows:

Filtration. Filters are available in a wide range of efficiencies and air resistance--from the common low efficiency hot air furnace filter to the high efficiency particulate air (HEPA or "absolute") filter. Selection should be made on the basis of respirable particle collection efficiency.

Electrostatic Precipitation. Electrostatic precipitators generally have high efficiencies and low air resistances, but require regular cleaning. If not properly cleaned, accumulated dirt can be reentrained in the ventilation air. These devices can also generate small quantities of ozone, itself a pollutant.

Air Washers. Most air washers are either of the spray type or packed cell type. Particulate removal efficiency is greater for the packed cell type and for larger, more wettable particles. ADL measured sulfur dioxide removal efficiency of both spray and packed cell washers in an ASHRAE-sponsored program to be 70-90% (Swanton, 1973). However, removal efficiencies for other gases at low ambient concentrations are almost unknown. If chemical agents are added to control acidity or the growth of micro-organisms, demisters should be used to prevent spray carryover.

Gas Sorbents. Activated carbon has been used in special applications to remove odors and ozone (Sabersky, et al., 1973), and is frequently used in electrostatic room air cleaners to remove ozone generated by the cleaner itself. Again, during previous in-house research for ASHRAE, ADL has measured removal of sulfur dioxide from ambient air by activated carbon to be 80-90% (Swanton, 1973).

3. Indoor Air Quality Standards

Almost no attention was focused towards indoor air quality standards until about 1973 when voluntary standards were published by ASHRAE in its Standard 62-73, "Natural and Mechanical Ventilation." The air quality provisions of this standard are somewhat confusing, relatively controversial, and almost unknown within the HVA/C design engineering industry. As shown in Table IX-1, two sets of standards are given in ASHRAE 62-73. One is stated to be based on existing outdoor air quality or air cleaning technology, and the other on one-tenth of the Threshold Limit Values (TLV) for industrial environments. For comparison, the Federal ambient air quality standards are also listed in Table IX-1.

ASHRAE Standard 62-73 may not have been intended to apply to both industrial and nonindustrial environments; however, the document does not state any such limitation. The TLV/10 values appear to be excessively stringent in the following cases.

a) The carbon monoxide TLV/10 value of 5600 $\mu g/m^3$ is about half the Federal ambient secondary air quality standard. This TLV/10 value will be even lower (about 4000 $\mu g/\ell$) if the current TLV value is lowered as proposed by OSHA. For comparison, the Japanese indoor air quality code specifies a limit of 11,200 $\mu g/m^2$ (10 ppm) for carbon monoxide (Araki and Katsumi, 1974 and Suzuki, 1974).

b) The TLV/10 value of 20 $\mu g/m^3$ for photochemical oxidants is one-eighth of the Federal ambient standard listed in Table IX-1. The U.S. Navy recently lowered the oxidant limit in nuclear submarines from 100 $\mu g/m^3$ to 40 $\mu g/m^3$; however, this was done for the purpose of minimizing rubber cracking rather than for the purpose of health effects.

The non-TLV ASHRAE standards for carbon monoxide and photochemical oxidants are three times the Federal ambient standards, about the same for sulfur dioxide and particulates[3], twice the nitrogen dioxide standard; and 25-times the hydrocarbon standard. The basis for these ASHRAE standards is stated to be that ambient outdoor air in many major cities either meets these standards or will meet them when passed through minimal air treatment systems (filters, heaters, coolers, humidifiers, etc.). ADL believes this is questionable, and that the rationale for different levels than the Federal ambient standards should be further reviewed and clarified. Epidemiological studies should be included in this review (Mitchell, et al., 1974, and Keller, et al., 1975).

The ASHRAE requirement that odor be judged unobjectionable by a panel of 10 untrained subjects should specify the percentage of the panelists that must agree on the findings. There are no Federal odor regulations.

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[3] For comparison, the Japanese indoor air quality code specifies a limit of 150 $\mu g/m^2$ for respirable particles (Araki and Katsumi, 1974; Suzuki, 1974).

TABLE IX-1

COMPARATIVE AIR QUALITY STANDARDS

Pollutant	Averaging Time	ASHRAE Standard 62-73		National Ambient[a]	
		Table I	TLV/10	Primary	Secondary
Particulate matter [a]	Annual geometric mean	60 μg/m^3		75 μg/m^3	60 μg/m^3
	24 hr	150 μg/m^3	10,000 μg/m^3	260 μg/m^3	150 μg/m^3
Sulfur dioxide	Annual arithmetic mean	80 μg/m^3		80 μg/m^3 (0.03 ppm)	
	24 hr	400 μg/m^3	1,300 μg/m^3 (0.5 ppm)	365 μg/m^3 (0.14 ppm)	
	3 hr				1,300 μg/m^3 (0.5 ppm)
Carbon monoxide	8 hr	30,000 μg/m^3	5,600 μg/m^3 (5 ppm)	10,000 μg/m^3 (9 ppm)	Same as primary
	1 hr			40,000 μg/m^3 (35 ppm)	
Photochemical oxidants[b]	1 hr	500 μg/m^3	20 μg/m^3 (0.01 ppm)	160 μg/m^3 (0.08 ppm)	Same as primary
Nonmethane hydrocarbons	3 hr	4,000 μg/m^3	36,000 μg/m^3 (10 ppm Hexane)	160 μg/m^3 (0.044 ppm hexane)	Same as primary
Nitrogen dioxide	Annual arithmetic mean	200 μg/m^3	1,000 μg/m^3 (0.5 ppm)	100 μg/m^3 (0.05 ppm)	Same as primary
Odor		c			

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[a] National Primary Standards: the levels of air quality necessary, with an adequate margin of safety, to protect the public health.

National Secondary Standards: the levels of air quality necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant.

National standards other than those based on annual arithmetic means or annual geometric means are not to be exceeded more than once per year (Federal Register 1971 and 1973).

[b] Indoor oxidant limits proposed by FDA and Canadian Standards Association are 0.05 ppm (100 μg/m^3) and 0.04 ppm (80 μg/m^3), respectively (Mueller, et al., 1973).

[c] Odor judged unobjectionable by a panel of 10 untrained subjects.

SOURCE: ASHRAE Standard 62-73; the Federal Register.

4. Levels of Indoor Air Pollution

Existing levels of indoor air pollution have not been well defined. Major reasons are interpretation of the Clean Air Act of applying only to outdoor air (Doggett and Freidman, 1973), and the common assumption that indoor air is cleaner than outdoor air.

Literature on this subject was reviewed by Benson, et al., in 1972 and found to be highly limited, primarily to SO_2, CO, CO_2, and particulates. The data was concluded to be sufficient only to suggest tentative indoor/outdoor pollution relationships. For example, indoor levels were usually found to be lower for coarse particulates and reactive gases, about the same as outdoors for fine particulates and nonreactive gases, and higher for micro-organisms. Peak values indoors were usually lower and occurred later than outdoors. Indoor generation rates, ventilation rates, and infiltration rates were not discussed, and additional experimental work was stated to be badly needed.

It would be useful to include a table of representative concentrations of indoor air pollutants for comparison with the table of air quality standards in the previous section, but not enough data has been found to ensure adequate representation. Concentrations vary greatly with location, season, type of building, ventilation and infiltration rates, etc. Additional studies are needed, such as the recent correlation of ventilation, air purification, and outdoor pollution conditions with concentrations of 6 air pollutants inside 11 buildings (Thompson, et al., 1973).

The most meaningful indoor air pollution levels for this study will be for those pollutants that are generated indoors. To date, the only such data available relate to tobacco smoke, gas stove emissions, and odor, as discussed below. These data are also very limited, but provide rough estimates of exposures in selected indoor environments.

a. Tobacco Smoke

CO and particulate concentrations in room air due to cigarette smoking were studied by Bridge and Corn (1972) at ventilation rates of about 5 cfm per smoking person. The average CO concentrations were equal to, or slightly less than, the Federal ambient air quality standard of 10,000 $\mu g/m^3$, but particulate concentrations were calculated to be thirty to sixty times the Federal ambient air quality standard of 75 $\mu g/m^3$.

CO and particulate concentrations indoors due to cigarette smoking were studied by Elliott and Rowe (1975). Measurements were made on 19 days in three arenas where attendance was 2,000 to 14,000. Ventilation and infiltration rates were not reported. Average CO values ranged from slightly less than the Federal ambient air quality standard of 10,000 $\mu g/m^3$ to almost three times that value. Particulate concentrations ranged from two to eight times the Federal ambient air quality standard of 75 $\mu g/m^3$.

Particulate concentrations due to cigarette smoking were calculated from measured nicotine concentrations in air by Hinds and First (1975) to be as follows:

Location	No. of Samples	Average Calculated Tobacco Smoke Particulates ($\mu g/m^3$)
Airline Waiting Room	2	120
Restaurant	4	200
Cocktail Lounge	3	400
Student Lounge	1	110

These values are 1.5 to 5 times the Federal ambient air quality standard of 75 $\mu g/m^3$. Again, ventilation and infiltration rates were not reported.

b. Gas Stove Emissions

NO_2 and CO concentrations in conventional kitchens with gas stoves were measured by Elkins et al. (1974) and Cote, et al. (1974), as shown in Table IX-2. Average NO_2 levels were found in most cases to exceed the Federal ambient air standard of 100 $\mu g/m^3$ and to be twice the outdoor concentrations in all cases. Average CO levels in 60 kitchens were only 60-80% of the Federal ambient air standard of 10,000 $\mu g/m^3$, but these concentrations were also about twice the outdoor concentrations in the three cases where outdoor levels were measured. While ventilation and infiltration rates were generally not reported, Cote, et al., found that vented stove hoods removed about half of the emissions.

c. Odor

A recent survey of odor problems inside conventional buildings by Leonardos and Kendall (1971) indicated that complaints about tobacco smoke odor, cooking odor, and body odor are frequent in residences, meeting rooms, and restaurants.

C. IMPACT OF ASHRAE 90 ON INDOOR AIR POLLUTION

The provisions of ASHRAE 90 that affect indoor air pollution are cooling with outdoor air and decreased ventilation and infiltration. The proposed provisions are discussed below.

1. Cooling with Outdoor Air

Section 5.6 of ASHRAE 90 requires cooling with outdoor air under certain conditions. It is not required when the quality of the outdoor

TABLE IX-2

GAS KITCHEN AND OUTDOOR CONCENTRATIONS OF NO_2 AND CO

(Indoor, $\mu g/m^3$/Outdoor, $\mu g/m^3$)

Reference	NO_2 (24-hour average)	CO (8-hour average)
Elkins (average of 51 summer samples and 70 winter samples in 121 kitchens)	148/68	*
Elkins (average of 69 winter samples in 69 kitchens)	108/58	-
Cote (average of 24-30 winter days of monitoring in 3 kitchens)	87/40	6000/2800

*One hour CO average of 57 winter samples in 57 kitchens during cooking was 8100 $\mu g/m^3$ ± 7400 $\mu g/m^3$.

air is so poor as to require extensive air purification. "Poor air" is not clearly defined, but an example might be Los Angeles during a smog alert. This method of cooling is common as presently practiced and involves high ventilation rates which will probably result in indoor air quality that is essentially the same as outdoor air. Thus, in terms of ASHRAE 90's impact on conventional practice, the expanded use of outdoor air for cooling will have a negligible effect.

2. Decreased Ventilation and Infiltration

Section 5.3.2.3 of ASHRAE 90 requires that ventilation air conform to ASHRAE Standard 62-73, "Natural and Mechanical Ventilation," using minimum ventilation rates (except for special occupancy or process requirements). These standards permit a reduction in outside air from 100% to 15% of the ventilation air if the recirculated air is purified to meet the air quality discussed above, provided that the outdoor air volume is at least 5 cfm/person. In interpreting the document for purposes of estimating annual energy consumption (see Chapter II), the ventilation of the prototypical conventional buildings was reduced as follows:

	Ventilation (cfm/ft.^{2})		
	Conventional	ASHRAE 90 Modified	Reduction (%)
Single-Family Residence	0	0	0
Multi-Family Low-Rise	0.05	0.025	50
Office	0.25	0.148	41
Retail Store	0.30	0.216	28
School	0.50	0.25	50

It should be noted that the single-family residence is the only category listed above which is not in compliance with ASHRAE 62-73, which requires a minimum of 5 to 20 cfm/person.

Section 4.5.3 of ASHRAE 90 requires that window and door leakage be reduced to less than 0.5 to 1.25 cfm/ft. of crack in a 25 mph wind, and that all openings in the exterior envelope be sealed. Again, in interpreting ASHRAE 90 for energy calculations, the infiltration of the prototypical conventional buildings were reduced as follows:

	Infiltration (Air Changes/Hour)		
	Conventional	ASHRAE 90 Modified	Reduction (%)
Single-Family Residence	1.0	0.93	7
Multi-Family Low-Rise and Nonresidential Buildings	0.5	0.3	40

The major effect of these reductions is expected to be decreased contamination from outdoor sources and increased contamination from indoor sources. The decreased contamination from outdoor sources can be calculated using theoretical models (Shair and Heitner, 1974, and Hales, et al., 1974), but the increased contamination from indoor sources cannot be calculated until indoor pollutant emission rates are known. The net effect of reduced ventilation and infiltration will be beneficial where outdoor sources predominate and detrimental where indoor sources predominate.

A beneficial effect of reduced ventilation and infiltration can be expected during smog alerts where ozone from outdoor sources will decay rapidly indoors due to its reactivity (Thompson, et al., 1973; Sabersky, et al., 1973; and Shair and Heitner, 1975). However, this effect for a single pollutant does not mean that one would be generally better off indoors than outdoors. Until additional data on indoor pollution generation rates become available, the relative importance of outdoor and indoor sources is uncertain.

Existing information on indoor air pollution levels suggests that the most adverse effect of the proposed reductions in ventilation and infiltration will be exposure of nonsmokers to higher particulate (and possible CO) concentrations due to tobacco smoking. As discussed in the previous section, particulate concentrations in several conventional smoking spaces have been reported to be at least 1.5 to 5 times higher than the ambient air quality standard of 75 $\mu g/m^3$. At lower ventilation and infiltration rates, the particulate concentrations will be increased by roughly proportional amounts, as follows:

	Average Reduction of Ventilation and Infiltration (%)	Approximate Increase In Pollution Level (%)
Single-Family Residence	3.5	4
Multi-Family Low-Rise	45	82
Office	40	67
Retail Store	34	52
School	45	82

In view of the high present concentrations of cigarette smoke particulates these increases would appear to be excessive, and that smoking spaces in public buildings should be ventilated at ASHRAE 62-73 recommended rates rather than the minimum rates. ADL believes that reduced infiltration will lead to greater demand for separate smoking and nonsmoking zones in public buildings and corresponding needs for different ventilation approaches.

In most residential buildings, the only apparent solution may be education of both the designer and occupant as to the hazard and preventive measures (exhaust fans, open windows, and air purifiers). Air cleaning techniques for reducing tobacco smoke are discussed by McNall (1974).

These reductions in ventilation and infiltration can also be expected to result in greater dissatisfaction with odor quality. A solution to this problem may be the development of improved odor control techniques.

Lower ventilation rates (as low as 5 cfm/person) and lower infiltration rates (no minimum) than those listed above are permissible under ASHRAE 90, and they will probably be used by design engineers. In unventilated structures (i.e., single-family residences), infiltration might be reduced to such low levels that contaminants and odors generated indoors would build up to hazardous or annoying concentrations, furnaces would malfunction due to lack of draft, and kitchen and bathroom exhaust fans would be ineffective unless supply air inlets are provided. These problems would be most severe in cold weather and in buildings where doors and windows are opened infrequently.

An example of this problem is NO_2 in single-family residential kitchens with gas stoves. As discussed in the previous section, NO_2 concentrations in conventional kitchens with gas stoves were found in many cases to exceed the Federal ambient air standard of 100 $\mu g/m^3$ and to be twice the outdoor concentrations in all cases. In very tight, unventilated buildings these concentrations could increase to several times the Federal standard.

ADL would not expect this problem to occur in multi-family apartments where central exhaust systems are being used, nor in single-family residences, if provided with 5 to 20 cfm/person of ventilation air as required by ASHRAE 62-73.

A solution to possible gas stove problems would appear to be the installation of vented stove hoods. However, to be completely effective, supply air in addtion to infiltration air should be provided.

The many residential indoor air pollution sources identified in the previous section suggest that additional similar problems will arise. However, insufficient data are available on emission rates, composition, and emission periods to permit an accurate quantification of the potential hazards.

3. Compliance with Air Quality Requirements

Air quality requirements are not mentioned in the systems analysis approach (Section 10) of ASHRAE 90 and could be overlooked by some designers. The addition of a brief statement of air quality requirements would eliminate this possibility.

The prescriptive/performance approach to ASHRAE 90 includes air quality requirements only by reference to ASHRAE 62-73. These requirements could be overlooked by design engineers. Those who study the requirements thoroughly might not comply adequately because the requirements are confusing, controversial, and possibly not feasible. The confusing and controversial aspects were discussed in the section on air quality standards. Feasibility issues are as follows:

- *Purification of Recirculated Air* - The technical feasibility of purifying recirculated air as specified in ASHRAE 62-73 has been demonstrated for particulate pollutants, but not for all gaseous pollutants (especially long-term operation and maintenance). The economics of achieving the latter are also uncertain.

- *Air Quality Monitoring* - Sampling and analysis of ventilation air are required by ASHRAE 62-73 where there is "reasonable expectation that air quality is unacceptable." In many cases, however, methods of sampling and analysis are either not specified, not sensitive enough, or possibly too costly.

D IMPACT OF REDUCED HUMIDITY CONTROL ON HABITABILITY

Sections 5.3.2 and 5.4.2 of ASHRAE 90 state that relative humidity in humidified spaces in winter should not be increased above 30%. In summer, humidistats should be set to comply with ASHRAE 55-74, "Thermal Environmental Conditions for Human Occupancy," at minimum energy use (about 60% RH at 78°F). These conditions are only slightly more restrictive than the 20 to 65% RH range specified in ASHRAE 55-74 and will apply primarily to office buildings.

The literature was surveyed to assess the impact of reduced humidity control on health (see Appendix D). No significant adverse effect on the general population was found. This conclusion is based on short-term laboratory studies with healthy human subjects in which relative humidity effects on respiratory function and water evaporation from skin was monitored.

Adverse effects on middle-aged persons with respiratory disorders were noted in one study. A four-hour exposure to 22°C and 92% RH apparently resulted in increased shortness of breath, increased difficulties in breathing, and increased airways resistance. However one would not expect these adverse effects would occur at the much more moderate ASHRAE 90 recommended humidities.

The most common complaints about relative humidity occur in winter and concern irritation of the upper respiratory system, postnasal drips, and coughs due to dry air (Ayres, 1971). However, recent evidence suggests that these effects are not due to low humidity, but to other winter conditions such as increased air pollution.

Many *in vitro* (outside living bodies) studies have dealt with the effects of relative humidity on the viability of micro-organisms. The effects appear to vary markedly with micro-organism species and experimental conditions. These effects are not directly transferable to natural situations, and in some cases, appear contradictory.

A few epidemiological studies discuss correlations between relative humidity and absenteeism, colds, and asthma, but the correlations have not been confirmed.

E. CONCLUSIONS AND RECOMMENDATIONS

The principal impact of ASHRAE 90 on health, safety, and welfare of building occupants will result from reduced ventilation and infiltration. Cooling with outdoor air and reduced humidity control are not expected to have significant effects.

The ASHRAE 90 provisions for decreased ventilation and infiltration will greatly increase the importance of indoor air pollution sources. Recirculation of ventilation air and use of air purification equipment (and its resulting cost) is expected to become more important.

The reduced ventilation and infiltration values assumed for energy calculation purposes are expected to result in excessively increased exposures of nonsmokers to cigarette smoke particulates, an increase in odor complaints, and demands for separate smoking and nonsmoking areas. To minimize these problems, smoking spaces in public buildings should be ventilated at ASHRAE 62-73 recommended rates rather than the minimum rates, and improved odor control techniques should be developed.

Lower ventilation and infiltration rates than those used for energy calculation purposes are permissible under ASHRAE 90. These rates could result in addtional adverse effects, such as excessive NO_2 levels in kitchens with gas stoves. A solution to this problem may be installation of vented stove hoods.

Additional similar problems are expected to arise under ASHRAE 90 but insufficient data are available on pollutant sources, species, concentrations, and emission periods to permit quantitative evaluation. Furthermore, indoor air quality standards require additional review and clarification.

Purification of ventilation air is technically feasible for particulate contaminants but has not yet been demonstrated for all gaseous contaminants--especially the aspects of extended operation and maintenance. The economics of gaseous contaminant removal are also uncertain.

Further study of the impact of energy conservation on habitability is recommended. Major needs are as follows:

- Indoor Sources

  Measure indoor source pollutants, emission rates, and resultant concentrations in various types of buildings. Include consumer products and appliances which lead to indoor air pollution.

- Control Systems

  Measure the effectiveness of selected control systems for the removal of particulate and gaseous pollutants (including odor). A laboratory and field study.

- Health Effects

  Develop a set of criteria or guidelines for the determination of acceptable indoor air quality. Include review of indoor air quality standards in ASHRAE 62-73 and epidemiological studies.

- Odor

  Develop systematic odor measurement programs to characterize odor sources and evaluate odor control systems.

Some of this information can be obtained from the literature, but the majority will require new laboratory and field measurement programs.

APPENDICES

APPENDIX A: COMPARATIVE HVA/C DESIGN CAPACITIES OF PROTOTYPICAL BUILDINGS

APPENDIX B: ACTUAL ENERGY CONSUMPTION OF PROTOTYPICAL BUILDINGS

APPENDIX C: COST INDICES

APPENDIX D: EFFECTS OF RELATIVE HUMIDITY ON HEALTH

TABLE A-1

LOW-RISE APARTMENT BUILDING: COMPARATIVE HVA/C DESIGN CAPACITIES, CONVENTIONAL VERSUS ASHRAE 90

PROTOTYPICAL STRUCTURES

	Heating		C
	Capacity (1000 Btu)	Sq. Ft./1000/Btu	Capacity (tons)
CONVENTIONAL			
Northeast	513	35.1	31
North Central	565	31.8	33
West	713	25.2	30
South	630	28.6	35
ASHRAE 90-75 MODIFIED			
Northeast	270	66.7	21
North Central	360	49.9	20
West	291	61.8	22
South	269	66.9	23

SOURCE: Kling-Lindquist, Inc., based on strict interpretation of ASHRAE 90-75.

TABLE A-1

MPARATIVE HVA/C DESIGN CAPACITIES, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED PROTOTYPICAL STRUCTURES

Heating		Cooling	
Capacity (1000 Btu)	Sq. Ft./1000/Btu	Capacity (tons)	Sq. Ft./Ton
513	35.1	31	577
565	31.8	33	554
713	25.2	30	592
630	28.6	35	510
270	66.7	21	853
360	49.9	20	887
291	61.8	22	818
269	66.9	23	786

ased on strict interpretation of ASHRAE 90-75.

TABLE A-2

OFFICE BUILDING: COMPARATIVE HVA/C DESIGN CAPACITIES, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIE

STRUCTURES

	Heating		C
	Capacity (1000 Btu)	Sq. Ft./1000/Btu	Capacity (tons)
CONVENTIONAL			
Northeast	1300	31.2	162
North Central	1360	29.8	175
West	1313	30.8	126
South	1317	20.8	167
ASHRAE 90-75 MODIFIED			
Northeast	834	48.6	93
North Central	876	46.2	100
West	940	43.1	106
South	934	43.4	104

SOURCE: Kling-Lindquist, Inc., based on strict interpretation of ASHRAE 90-75.

TABLE A-2

VE HVA/C DESIGN CAPACITIES, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED PROTOTYPICAL STRUCTURES

Heating		Cooling	
Capacity (1000 Btu)	Sq. Ft./1000/Btu	Capacity (tons)	Sq. Ft./Ton
1300	31.2	162	250
1360	29.8	175	232
1313	30.8	126	320
1317	20.8	167	243
834	48.6	93	435
876	46.2	100	402
940	43.1	106	381
934	43.4	104	391

nc., based on strict interpretation of ASHRAE 90-75.

TABLE A-3

RETAIL STORE: COMPARATIVE HVA/C DESIGN CAPACITIES, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED STRUCTURES

	Heating		
	Capacity (1000 Btu)	Sq. Ft./1000/Btu	Capacit (tons)
CONVENTIONAL			
Northeast	1884	17.2	182
North Central	2272	14.3	193
West	2063	15.7	147
South	1824	17.8	189
ASHRAE 90-75 MODIFIED			
Northeast	948	34.2	120
North Central	1298	25.0	123
West	1048	30.9	125
South	935	34.6	124

SOURCE: Kling-Lindquist, Inc., based on strict interpretation of ASHRAE 90-75.

TABLE A-3

HVA/C DESIGN CAPACITIES, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED PROTOTYPICAL STRUCTURES

Heating		Cooling	
Capacity (1000 Btu)	Sq. Ft./1000/Btu	Capacity (tons)	Sq. Ft./Ton
1884	17.2	182	178
2272	14.3	193	168
2063	15.7	147	220
1824	17.8	189	173
948	34.2	120	270
1298	25.0	123	263
1048	30.9	125	258
935	34.6	124	260

nc., based on strict interpretation of ASHRAE 90-75.

TABLE A-4

SCHOOL BUILDING: COMPARATIVE HVA/C DESIGN CAPACITIES, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFI

STRUCTURES

	Heating		
	Capacity (1000 Btu)	Sq. Ft./1000/Btu	Capacit (tons)
CONVENTIONAL			
Northeast	2709	14.8	219
North Central	3402	11.8	238
West	3467	11.6	169
South	3094	12.9	252
ASHRAE 90-75 MODIFIED			
Northeast	1213	33.0	123
North Central	1661	24.1	130
West	1326	30.2	133
South	1207	33.1	131

SOURCE: Kling-Lindquist, Inc., based on strict interpretation of ASHRAE 90-75.

TABLE A-4

HVA/C DESIGN CAPACITIES, CONVENTIONAL VERSUS ASHRAE 90-75 MODIFIED PROTOTYPICAL STRUCTURES

Heating		Cooling	
Capacity (1000 Btu)	Sq. Ft./1000/Btu	Capacity (tons)	Sq. Ft./Ton
2709	14.8	219	182
3402	11.8	238	168
3467	11.6	169	236
3094	12.9	252	159
1213	33.0	123	325
1661	24.1	130	307
1326	30.2	133	300
1207	33.1	131	304

, based on strict interpretation of ASHRAE 90-75.

TABLE B-1

SUMMARY OF ANNUAL ENERGY CONSUMPTION FOR PROTOTYPICAL SINGLE-FAMILY RESIDENCE

	Northeast (1,600 sq. ft.)	North Central (1,600 sq. ft.)	South (1,675 sq. ft.)
CONVENTIONAL			
Electricity (kwh)	18,600	12,300	36,501
(1000 Btu/sq. ft.)	39.8	26.2	74.4
Oil (gallons)/gas (1000 cub. ft.)	1,557 (oil)	259 (gas)	--
(1000 Btu/sq. ft.)	137.2	170.0	--
Total Energy (1000 Btu/sq. ft.)	177.0	196.2	74.4
ASHRAE 90-75 MODIFIED			
Electricity (kwh)	15,793	11,295	33,024
(1000 Btu/sq. ft.)	33.7	24.[illegible]	67.3
Oil (gallons)/gas (1000 cub. ft.)	1,330 (oil)	212.7 (gas)	--
(1000 Btu/sq. ft.)	117.2	139.6	--
Total Energy (1000 Btu/sq. ft.)	150.9	163.7	67.3

SOURCE: Kling-Lindquist, Inc., estimates.

TABLE B-1

NNUAL ENERGY CONSUMPTION FOR PROTOTYPICAL SINGLE-FAMILY RESIDENCE

	Northeast (1,600 sq. ft.)	North Central (1,600 sq. ft.)	South (1,675 sq. ft.)	West (1,705 sq. ft.)
	18,600	12,300	36,501	49,505
	39.8	26.2	74.4	99.1
b. ft.)	1,557 (oil)	259 (gas)	--	--
	137.2	170.0	--	--
ft.)	177.0	196.2	74.4	99.1
	15,793	11,295	33,024	44,838
	33.7	24.1	67.3	89.8
b. ft.)	1,330 (oil)	212.7 (gas)	--	--
	117.2	139.6	--	--
ft.)	150.9	163.7	67.3	89.8

c., estimates.

TABLE B-2

SUMMARY OF ANNUAL ENERGY CONSUMPTION FOR LOW-RISE APARTMENT BUILDING

	Northeast (18,000 sq. ft.)	North Central (18,000 sq. ft.)	South (18,000 sq. ft.)	(18
CONVENTIONAL				
Electricity (kwh)	404,564	185,369	236,870	
(1000 Btu/sq. ft.)	76.7	35.1	44.9	
Oil (gallons)/gas (1000 cub. ft.)	22,595 (oil)	4,184 (gas)	4,088 (gas)	
(1000 Btu/sq. ft.)	177.0	244.1	238.5	
Total Energy (1000 Btu/sq. ft.)	253.7	279.2	283.4	
ASHRAE 90-75 MODIFIED				
Electricity (kwh)	258,530	98,321	114,762	
(1000 Btu/sq. ft.)	49.0	18.6	21.8	
Oil (gallons)/gas (1000 cub. ft.)	9,626 (oil)	2,925 (gas)	2,428 (gas)	
(1000 Btu/sq. ft.)	75.4	170.6	141.6	
Total Energy (1000 Btu/sq. ft.)	124.4	189.2	163.4	

SOURCE: Kling-Lindquist, Inc., based on computer simulation.

TABLE B-2

ANNUAL ENERGY CONSUMPTION FOR LOW-RISE APARTMENT BUILDING

	Northeast (18,000 sq. ft.)	North Central (18,000 sq. ft.)	South (18,000 sq. ft.)	West (18,000 sq. ft.)
	404,564	185,369	236,870	199,698
	76.7	35.1	44.9	37.9
. ft.)	22,595 (oil)	4,184 (gas)	4,088 (gas)	4,452 (gas)
	177.0	244.1	238.5	259.7
ft.)	253.7	279.2	283.4	297.6
	258,530	98,321	114,762	110,850
	49.0	18.6	21.8	21.0
. ft.)	9,626 (oil)	2,925 (gas)	2,428 (gas)	2,428 (gas)
	75.4	170.6	141.6	141.6
ft.)	124.4	189.2	163.4	162.7

., based on computer simulation.

TABLE B-3

SUMMARY OF ANNUAL ENERGY CONSUMPTION FOR OFFICE BUILDING

	Northeast (40,500 sq. ft.)	North Central (40,500 sq. ft.)	South (40,500 sq.ft.)	(40
CONVENTIONAL				
Electricity (kwh)	1,012,363	1,063,131	1,083,559	1
(1000 Btu/sq. ft.)	85.3	89.6	91.3	
Oil (gallons)/gas (1000 cub. ft.)	47,351 (oil)	7,380 (gas)	5,780 (gas)	
(1000 Btu/sq. ft.)	164.9	191.3	149.9	
Total Energy (1000 Btu/sq. ft.)	250.2	280.9	241.2	
ASHRAE 90-75 MODIFIED				
Electricity (kwh)	654,529	673,770	718,711	
(1000 Btu/sq.ft.)	55.1	56.8	60.6	
Oil (gallons)/gas (1000 cub. ft.)	11,821 (oil)	2,010 (gas)	1,509 (gas)	
(1000 Btu/sq. ft.)	41.2	52.1	39.1	
Total Energy (1000 Btu/sq. ft.)	96.3	108.9	99.7	

SOURCE: Kling-Lindquist, Inc., based on computer simulation.

TABLE B-3

F ANNUAL ENERGY CONSUMPTION FOR OFFICE BUILDING

	Northeast (40,500 sq. ft.)	North Central (40,500 sq. ft.)	South (40,500 sq.ft.)	West (40,500 sq.ft.)
	1,012,363	1,063,131	1,083,559	1,007,765
	85.3	89.6	91.3	84.9
. ft.)	47,351 (oil)	7,380 (gas)	5,780 (gas)	6,315 (gas)
	164.9	191.3	149.9	163.7
ft.)	250.2	280.9	241.2	248.6
	654,529	673,770	718,711	699,260
	55.1	56.8	60.6	58.9
. ft.)	11,821 (oil)	2,010 (gas)	1,509 (gas)	1,864 (gas)
	41.2	52.1	39.1	48.3
ft.)	96.3	108.9	99.7	107.3

., based on computer simulation.

TABLE B-4

SUMMARY OF ANNUAL ENERGY CONSUMPTION FOR RETAIL STORE

	Northeast (32,400 sq. ft.)	North Central (32,400 sq. ft.)	South (32,400 sq.ft.)
CONVENTIONAL			
Electricity (kwh)	2,131,757	2,250,342	2,308,039
(1000 Btu/sq. ft.)	224.6	237.1	243.1
Oil (gallons)/gas (1000 cub. ft.)	12,304 (oil)	1,627 (gas)	1,024 (gas)
(1000 Btu/sq. ft.)	53.5	52.7	33.2
Total Energy (1000 Btu/sq. ft.)	278.1	289.8	276.3
ASHRAE 90-75 MODIFIED			
Electricity (kwh)	1,427,332	1,391,802	1,539,713
(1000 Btu/sq. ft.)	150.4	146.6	162.2
Oil (gallons)/gas (1000 cub. ft.)	2,741 (oil)	616 (gas)	287 (gas
(1000 Btu/sq. ft.)	11.9	20.0	9.3
Total Energy (1000 Btu/sq. ft.)	162.3	166.6	171.5

SOURCE: Kling-Lindquist, Inc., based on computer simulation.

TABLE B-4

SUMMARY OF ANNUAL ENERGY CONSUMPTION FOR RETAIL STORE

	Northeast (32,400 sq. ft.)	North Central (32,400 sq. ft.)	South (32,400 sq.ft.)	West (32,400 sq. ft.)
	2,131,757	2,250,342	2,308,039	2,082,977
	224.6	237.1	243.1	219.4
. ft.)	12,304 (oil)	1,627 (gas)	1,024 (gas)	1,706 (gas)
	53.5	52.7	33.2	55.3
ft.)	278.1	289.8	276.3	274.7
	1,427,332	1,391,802	1,539,713	1,477,386
	150.4	146.6	162.2	155.6
. ft.)	2,741 (oil)	616 (gas)	287 (gas	411 (gas)
	11.9	20.0	9.3	13.3
ft.)	162.3	166.6	171.5	169.0

., based on computer simulation.

TABLE B-5

SUMMARY OF ANNUAL ENERGY CONSUMPTION FOR SCHOOL BUILDING

	Northeast (40,000 sq. ft.)	North Central (40,000 sq. ft.)	South (40,000 sq. ft.)
CONVENTIONAL			
Electricity (kwh)	541,926	563,814	574,759
(1000 Btu/sq. ft.)	46.2	48.1	49.0
Oil (gallons)/gas (1000 cub. ft.)	26,684 (oil)	3,813 (gas)	3,704 (gas)
(1000 Btu/sq. ft.)	94.1	100.1	97.2
Total Energy (1000 Btu/sq. ft.)	140.3	148.2	146.3
ASHRAE 90-75 MODIFIED			
Electricity (kwh)	393,758	398,117	415,097
(1000 Btu/sq. ft.)	33.6	34.0	35.4
Oil (gallons)/gas (1000 cub. ft.)	12,121 (oil)	1,844 (gas)	1,351 (gas)
(1000 Btu/sq. ft.	42.7	48.4	35.5
Total Energy (1000 Btu/sq. ft.	76.3	82.4	70.9

SOURCE: Kling-Lindquist, Inc., based on computer simulation.

TABLE B-5

Y OF ANNUAL ENERGY CONSUMPTION FOR SCHOOL BUILDING

	Northeast (40,000 sq. ft.)	North Central (40,000 sq. ft.)	South (40,000 sq. ft.)	West (40,000 sq. ft.)
	541,926	563,814	574,759	526,113
	46.2	48.1	49.0	44.9
ft.)	26,684 (oil)	3,813 (gas)	3,704 (gas)	4,130 (gas)
	94.1	100.1	97.2	108.4
.)	140.3	148.2	146.3	153.3
	393,758	398,117	415,097	397,747
	33.6	34.0	35.4	33.9
ft.)	12,121 (oil)	1,844 (gas)	1,351 (gas)	1,566 (gas)
	42.7	48.4	35.5	41.1
t.	76.3	82.4	70.9	75.1

, based on computer simulation.

TABLE C-1

REGIONAL COST INDICES,* 1975

	Northeast	North Central	South	West
General Building Trades	101.3	98.7	88.9	99.4
Mechanical				
Equipment	99.9	100.6	102.8	101.5
Equipment and Labor	99.0	102.7	90.6	102.9
Electrical				
Equipment	99.7	103.3	100.0	101.1
Equipment and Labor	101.2	99.0	90,9	99.1

SOURCE: Based on 105 major U.S. cities reported by R. S. Means, Co.

APPENDIX D

EFFECTS OF RELATIVE HUMIDITY ON HEALTH

A. INTRODUCTION

This discussion of the effects of relative humidity on health is based on a brief survey of selected literature, which is summarized in Table D-1. An in-depth literature search might yield conflicting reports.

Laboratory studies with humans involved primarily young, healthy individuals and short-term exposures. No reports of long-term effects in atmospheres with extreme relative humdities or changing temperatures were found.

In vitro studies (outside living bodies) and epidemiological studies of relative humidity and virus relationships cannot be directly compared to confirm or support individual findings. The *in vitro* studies are conducted in controlled environments without atmospheric contaminants and are of short duration. Also, the behavior of airborne viruses depends on the environment of the culture before aerosolization.

B. LABORATORY STUDIES WITH HUMANS

1. Effects of Ambient Humidity on Respiratory Function

In several recent studies by Anderson et al., 1972, 1973, 1974, healthy young human subjects were exposed in a climate chamber maintained at a constant atmospheric temperature of 23°C to decreasing relative humidities of 50, 30, or 10% for periods of 3.5-4 or 78 hours. The ventilating air supplied during these experiments was particle-free and without condensation nuclei. Particle generation from the subjects and their special all-cotton dress was also negligible. No significant changes were observed in nasal mucus flow or in nasal airflow resistance in these subjects following a stay of 3.5 to 78 hours in the various atmospheres. The authors commented that their findings clearly show that the nose has a humidifying capacity sufficient to compensate for even sustained exposures to dry air. The fact that the mucus flow rate was higher during the last part of the 78-hour dry period (when nasal respiration was more than tenfold increased during a 20-minute period of exercise) than in the first part supports these findings. Sustained exposure to dry air also did not influence the cross-sectional area of the nasal and tracheobronchial airways. These results have important implications for human health since the nasal mucosa and mucociliary flow are important defense mechanisms against inhaled viable and nonviable pathogens.

During the four-hour exposure, humidity changes from a maximum of 70% to 10% and back from 10% to 70% did not affect the subjects' perception of humidity. However, the change in the humidity level did cause a highly significant change in the subjective perception of temperature. When the humidity was decreased, temperature was perceived as lower, and when humidity increased, temperature was perceived as higher than during constant humidity conditions. This effect was ascribed to humidity desorption and absorption phenomena in the clothing and on the skin in periods with a decrease or rise in humidity, respectively, creating a transitional cooling or heating effect. During the 78-hour exposure, some subjects seemed to be able to detect some discomfort in the dry period, but the votings were highly variable and did not correspond to the constant dry conditions. Likewise, there were no complaints of dryness of the body surfaces and the skin resistance remained unaltered during the experiment.

High ambient relative humdity also had no effect on respiratory function in similar short-term experienced by Melville et al., 1970. Forty-four healthy, young or middle-aged subjects exposed in a climate chamber to constant atmospheric temperature and relative humidity of 21°C and 93%, respectively, for six hours showed no significant changes in specific airway resistance. When the duration of the exposure period was increased to 71 hours (at 23°C and 83% RH), similar effects were obtained in three subjects less than 35 years of age.

In contrast, middle-aged subjects with a known respiratory disorder (e.g., emphysema, bronchitis, silicosis, tuberculosis) experienced increasing shortness of breath and difficulties in breathing following a four-hour exposure in a climate chamber maintained at 22°C and 92% RH (Josenhans, et al., 1969). Measurements of airway reistance showed significant increases when either tap or distilled water was used to humidify the chamber air, although the increase was greater when tap water was employed. No significant changes in functional residual capacity occurred with either humidifying agent. The authors concluded that these findings were explained by bronchoconstriction due to air contamination produced by tap water evaporation and also by assuming water retention in the airways when breathing air of high humidity.

These results indicate that older individuals with respiratory disease have impaired pulmonary function in atmospheres of high relative humidity. However, there is no evidence in the literature examined of adverse effects of extreme ranges (10-93%) of relative humidity at room temperature on respiratory function of healthy individuals after short-term exposure. Andersen, et al., (1974) comment that their findings provide ample evidence to question the stated importance of keeping indoor humidity above 30% RH at ordinary room temperatures. "Since the humdifying capacity of the normal nose is clearly sufficient to secure a normal function of the nasal mucus membranes, and since no great discomfort is experienced from any body surface, there is no apparent physiological need for artificial humidification of clean air. The results obtained are valid for clean air exposures at constant temperature, and not necessarily for exposure to air containing dust or other contaminants, or to conditions with changing temperatures. It is common knowledge that people often complain of dry air, mucus membrane troubles and dry skin during winter periods with subzero temperature. It is suggested that these complaints are not caused by low humidity per se, but by one or several of the other factors occurring simultaneously with dry air in the winter, i.e., the low outside temperature, higher dust levels or higher SO_2 levels. A more rational procedure might then be the elimination of these other factors instead of the relatively expensive artificial humidification of indoor air."

2. Effects of Ambient Humidity on Water Evaporation from Skin

Varying results have been obtained by different investigators in experiments designed to monitor water evaporation from normal skin of human subjects exposed to various environmental conditions. In studies by Lamke and Wedin, 1971, evaporation from the skin was measured in healthy individuals exposed in a climate chamber to a constant air temperature of 28°C and relative humidities of 20, 40, or 80% until skin temperature and evaporation were constant. No statistically significant changes in evaporation occurred in the different atmospheres. The authors considered that at 28°C the water supply to the surface skin is insignificant compared with the evaporation and transport capacity of the passing air and that water which reaches the surface will easily be evaporated and transported away whether the air is moist or dry. They note, however, that other investigators have found a slight decrease in evaporation from the skin when the humidity of the ambient air is increased.

The latter finding is supported by studies of Grice et al., 1972, in normal subjects with sweating abolished on the anterior surface of the forearm. In these subjects, measurements of transepidermal water loss from an encapsulated area of skin were conducted at constant skin temperature and at ambient humidity levels of 2-3, 22-27, 43-52 and 73-77%. The results showed a 2- to 3-fold increase in the rate of transepidermal water loss with an increase in relative humidity from 2-3% to 30-50%. By 73-77% RH, the rate of water loss had fallen to or near the initial rate. The authors suggest that the rising ambient humidity increases the permeability of the stratum corneum by increasing the water content so that transepidermal water loss rises. As the ambient humidity continues to rise, there is a decreasing vapor pressure difference between the stratum corneum surface and ambient air and the transepidermal water loss tends to fall.

C. *IN VITRO* STUDIES WITH BACTERIA AND VIRUSES

In a series of experiments by McDade and Hall, 1963, 1964, the survival rates of Staphylococcus aureus and several Gram-negative bacteria, which are known causes of some institutionally-acquired infections, were studied under constant atmospheric temperature (25°C) and varying humidity levels of 11, 53 or 85%. Squares of glass, ceramic tile and metal were inoculated in a broth of bacterial cell suspension prior to testing. After 7 days, fairly high recovery of viable organisms was obtained on all surfaces at 11% relative humidity. At 53 or 8% RH, die-away of all surface-exposed bacteria was accelerated and progressive after four hours. The authors concluded that the environmental RH tends to exert a pronounced effect on the viability of the surface-exposed bacteria studied.

Most information currently available on the behavior of airborne cells, however, has been collected by investigators studying aerosols held in static environments. Hatch and Dimmick, 1966, have reported that some investigators have shown that survival of bacteria was markedly influenced by humidity and temperature, and that the effects varied between bacterial species. Death of certain airborne bacteria has been observed to increase with rise in relative humidity, but contrary findings have also been reported. Maximal deaths rates were found between 50 and 60% RH, and death has been reported to occur at more than one rate. These authors caution of the difficulty of extrapolating these results to natural situations because of the dependence of airborne behavior on the history of environment of the culture before aerosolization.

The literature contains few reports on the influence of relative humidity and temperature on airborne viruses. The results must be interpreted in light of the culture medium employed, the type of cloud chamber used, the presence or absence of light and the methods of generating, sampling and assessing aerosols. In general, aerosolized influenza virus was shown to be inactivated rapidly at high (50-90%) relative humidities, but not at low (15-40%) relative humidities (Hemmes et al., 1960). The same was shown for measles virus, except that inactivation was more rapid at relative humidities of 60 to 80% than at higher relative humidities (DeJong and Winkler, 1964). In contrast, the inactivation of aerosolized and stored poliomyelitis virus was found to be slow at high (50-95%) relative humidities (Hemmes et al., 1960; Harper, 1961). According to Benbough, 1971, some investigators have concluded that viruses with structural lipids survived best in aerosols at low relative humidity, while ether-resistant viruses without structural lipids generally survived best at high humidities. Songer, 1967 examined the inactivation rates of many aerosolized viruses as a function of relative humidity and was unable to confirm this conclusion. In these studies, the optimum RH for survival of Newcastle disease virus and vesicular stomatis virus was found to be 10% when stored in the aerosol form. However, a RH of 90% favored generation survival.

D. EPIDEMIOLOGICAL STUDIES

The role of relative humidity in the transmission of airborne infection has been studied by Kingdon, 1959, for the Asian influenza epidemic year of 1957. Relative humidity data from meteorological records taken outdoors between the hours of 0800 and 2000 were shown to be related to the onset of influenza in October 1957 or January 1958 in the cities of Houston, Dallas, and Miami as determined by Public Health Service employee absenteeism data. These cities were chosen for consideration since they had sufficiently warm weather throughout the epidemic onset period to make the outdoor relative humidity data roughly equivalent to relative humidity indoors where people congregate. A sharp increase in the humidity ratio (which compared the number of hours at 86-95% RH favorable to infection by inhaled virus with the number of hours at 76-85% RH in which airborne virus would be killed by relative humidity effects) coincided with a rise in the 1957-58/1956-57 employee absenteeism ratio which took place in October, 1957 in Houston and Dallas, and in January 1958 in Miami. The author considered the 86-95% RH range to be favorable to infection because of the theoretical size and behavioral characteristics of droplets in an ambient atmosphere of less than 100% RH over time. The salt concentration in the droplet which may be high enough in the 86-95% range to dissociate the virus from an inhibitor was considered to be another contributing factor.

Unpublished data by Green, reported by Rohles, 1975, showed a 10% reduction in absenteeism among school children when the average relative humidity in school hours was increased from 22 to 45%. The location of the study was not specified. In a similar study, Swiss children had a 50% reduction in colds for pupils in humidified rooms from those in nonhumidified rooms (Rohles, 1975).

The seasonal variation in the incidence of asthma in the subtropical climate of Brisbane, Australia, was found by Derrick, 1965, to be positively correlated with temperature and dew point (as measure of absolute humidity), with a lag of one to two months, during the cooler months of May to October for the individual years 1959-1964. The correlation with relative humidity, measured at 1500 hour, was significant in the average year with one month's lag, but in only three of the six individual years. The author explained the association between weather and asthma largely by the production of allergens by some micro-organisms, possibly fungi. He theorized that the lag would represent the time taken for allergens to reach effective concentration after the inception of the production process.

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A. LABORATORY STUDIES WITH HUMANS

1. Effects of Ambient Humidity on Respiratory Function

No. Subjects and Sex	Age Yr.	Condition	Exposure Conditions				Effects	
			Temp °C	RH %	Time Hr.	Other		
53 males; 5 females	21-26	healthy	23 ± 0.3	10 30 50	3.5	"particle-free" environment; special all-cotton dress	No change in nasal mucus flow or nasal airway resistance by decreasing RH from 70% to 50, 30 or 10% or by maintaining a constant RH at 70%.	And
				70	8			
48 males	21-26	healthy	23 ± 0.3	10 30 50	4	As above	No change in subjective perception of RH following decrease in RH from 70% to 50, 30 or 10%. Temperature perceived to be lower with decreased RH and to be higher with increased RH.	And
				70	8			
8 males	21-26	healthy	23 ± 0.3	9	78	As above	No change in nasal mucus flow or nasal or tracheobronchial cross-sectional area after decrease in RH from 50% to 9%. No alteration in skin resistance or complaints of dryness of body surfaces. Increased weight loss per hour, and increased liquid consumption and urine volume.	And
				50	27			
44 males	28 <35; 16 >35	healthy	21	93	6	Air humidified by nebulizing tap water	No change in specific airway resistance.	Mel
3 males	<35	healthy	23	83	71	As above		
16 males	52	with respiratory disease	22	92	≥4	Air humidified by nebulizing tap or distilled water.	Significant increase in airway resistance. Subjects experienced increasing shortness of breath and difficulties in breathing. Increase in airway resistance greater with tap water than with distilled water. No change in functional residual capacity with either humidifying agent.	Jo

2. Effects of Ambient Humidity on Water Evaporation from the Skin

10 males; 6 females	21-60	healthy	28	20 40 80	--	--	No discomfort. No significant changes in evaporation from the skin in the different atmospheres. Only slight variations in skin temperature.	La
12[†] (sex not specified)	--	healthy	20-22	2-3[*] 23-27 43-52 73-77	0.5-1	--	Two to threefold increase in rate of transepidermal water loss with increase in RH from 2-3% to 30-50%. By 73-77% RH, the rate of transepidermal water loss had fallen to or near the initial rate.	Gr

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[†] Sweating abolished on the anterior surface of the forearm by painting with 4% poldine methosulphate. Capsule affixed to skin.

[*] Constant humidity maintained with saturated salt solution.

EFFECTS OF RELATIVE HUMIDITY ON HEALTH

AMS

n Respiratory Function

Exposure Conditions				Effects	Reference
Temp °C	RH %	Time Hr.	Other		
3 ± 0.3	10 30 50 70	3.5 8	"particle-free" environment; special all-cotton dress	No change in nasal mucus flow or nasal airway resistance by decreasing RH from 70% to 50, 30 or 10% or by maintaining a constant RH at 70%.	Andersen et al., 1972
3 ± 0.3	10 30 50 70	4 8	As above	No change in subjective perception of RH following decrease in RH from 70% to 50, 30 or 10%. Temperature perceived to be lower with decreased RH and to be higher with increased RH.	Andersen et al., 1973
3 ± 0.3	9 50	78 27	As above	No change in nasal mucus flow or nasal or tracheobronchial cross-sectional area after decrease in RH from 50% to 9%. No alteration in skin resistance or complaints of dryness of body surfaces. Increased weight loss per hour, and increased liquid consumption and urine volume.	Andersen et al., 1974
1	93	6	Air humidified by nebulizing tap water	No change in specific airway resistance.	Melville et al., 1970
3	83	71	As above		
2	92	≥4	Air humidified by nebulizing tap or distilled water.	Significant increase in airway resistance. Subjects experienced increasing shortness of breath and difficulties in breathing. Increase in airway resistance greater with tap water than with distilled water. No change in functional residual capacity with either humidifying agent.	Josenhans et al., 1969

Water Evaporation from the Skin

	20 40 80	--	--	No discomfort. No significant changes in evaporation from the skin in the different atmospheres. Only slight variations in skin temperature.	Lamke and Wedin, 1971
0-22	2-3* 23-27 43-52 73-77	0.5-1	--	Two to threefold increase in rate of transepidermal water loss with increase in RH from 2-3% to 30-50%. By 73-77% RH, the rate of transepidermal water loss had fallen to or near the initial rate.	Grice et al., 1972

face of the forearm by painting with 4% poldine
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rated salt solution.

TABLE D-1 (CONTINUED)

EFFECTS OF RELATIVE HUMIDITY ON HEALTH

B. *IN VITRO* STUDIES WITH BACTERIA AND VIRUSES

1. Effects of Relative Humidity on Surface-Exposed or Airborne Bacteria

Type	Strain	Exposure Conditions				Effects
		Temp °C	RH %	Time	Other	
Escherichia coli 0:126		25	8-11 52-56 82-86	1-7 da	Surface (glass, ceramic tile and metal) exposed	Greatly accelerated die-away of bacteria exposed on all surfaces at 52-86% RH after 24 and 48 hr. Kills at 82-86% RH were slightly faster than at 52-56% RH. Fairly high recovery of viable organisms at 8-11% RH after 7 da.
Pasteurella pestis	A-1122	26	20 37 50 65 87	1.5 hr	---	Accelerated death rate of aerosolized virus at 65 and 87% RH. Lower decay rates at 20-50% RH. Viability also dependent on diluent.
Proteus vulgaris		25	8-11 52-56 82-86	4-48 hr	Surface (glass, ceramic tile, and metal) exposed	Accelerated die-away of bacteria exposed on all surfaces at 52-86% RH after 24 and 48 hr. Best survival rate at 8-11% RH after 48 hr.
Proteus morgani		25	8-11 52-56 82-86	4-48 hr	As above	Accelerated die-away of bacteria exposed on all surfaces at 52-86% RH after 24 and 48 hr. Kills at 82-86% RH were slightly faster. Best survival rate at 8-11% RH after 48 hr.
Pseudomonas aeruginosa		25	8-11 52-56 82-86	1-7 da	As above	Greatly accelerated die-away of bacteria exposed on all surfaces at 52-86% RH after 24 and 48 hr. Kills at 82-86% RH were slightly faster than at 52-56% RH. Fairly high recovery of viable organisms at 8-11% RH after 7 da.
Salmonella derby		25	8-11	1-7 da	As above	As above
Staphylococcus aureus	80/81 phage type FDA 209	25	11 33 53 85	2-7 da	Surface (glass, ceramic , rubber and asphalt tile, stainless steel and silk sutures) exposed	Accelerated die-away of both 80/81 phage type and FDA 209 strains exposed on all surfaces at 53 and 85% RH after 2-7 da. Fairly high recovery of both strains at 11 and 33% RH after 4-7 da. Improved survival of FDA 209 strain on stainless and ceramic tile surfaces compared with other surfaces.

TABLE D-1 (CONTINUED)

EFFECTS OF RELATIVE HUMIDITY ON HEALTH

D VIRUSES

face-Exposed or Airborne Bacteria

Exposure Conditions			Effects	Reference
RH %	Time	Other		
8-11 52-56 82-86	1-7 da	Surface (glass, ceramic tile and metal) exposed	Greatly accelerated die-away of bacteria exposed on all surfaces at 52-86% RH after 24 and 48 hr. Kills at 82-86% RH were slightly faster than at 52-56% RH. Fairly high recovery of viable organisms at 8-11% RH after 7 da.	McDade and Hall, 1964
20 37 50 65 87	1.5 hr	---	Accelerated death rate of aerosolized virus at 65 and 87% RH. Lower decay rates at 20-50% RH. Viability also dependent on diluent.	Won and Ross, 1966
8-11 52-56 82-86	4-48 hr	Surface (glass, ceramic tile, and metal) exposed	Accelerated die-away of bacteria exposed on all surfaces at 52-86% RH after 24 and 48 hr. Best survival rate at 8-11% RH after 48 hr.	McDade and Hall, 1964
8-11 52-56 82-86	4-48 hr	As above	Accelerated die-away of bacteria exposed on all surfaces at 52-86% RH after 24 and 48 hr. Kills at 82-86% RH were slightly faster. Best survival rate at 8-11% RH after 48 hr.	McDade and Hall, 1964
8-11 52-56 82-86	1-7 da	As above	Greatly accelerated die-away of bacteria exposed on all surfaces at 52-86% RH after 24 and 48 hr. Kills at 82-86% RH were slightly faster than at 52-56% RH. Fairly high recovery of viable organisms at 8-11% RH after 7 da.	McDade and Hall, 1964
8-11	1-7 da	As above	As above	McDade and Hall, 1964
11 33 53 85	2-7 da	Surface (glass, ceramic, rubber and asphalt tile, stainless steel and silk sutures) exposed	Accelerated die-away of both 80/81 phage type and FDA 209 strains exposed on all surfaces at 53 and 85% RH after 2-7 da. Fairly high recovery of both strains at 11 and 33% RH after 4-7 da. Improved survival of FDA 209 strain on stainless and ceramic tile surfaces compared with other surfaces.	McDade and Hall, 1963

TABLE D-1 (CONTINUED)

EFFECTS OF RELATIVE HUMIDITY ON HEALTH

B. *IN VITRO* STUDIES WITH BACTERIA AND VIRUSES (continued)

2. Effects of Relative Humidity on Airborne Viruses

Type	Strain	Exposure Conditions			Effects
		Temp. °C	RH %	Time Hr.	
E. coli B T3 bacteriophage	--	23	10 35 90	1.5	Survival rate of stored airborne virus greatest at 90% RH. At 35% RH, survival was extremely poor; at 10% RH, survival was considerably improved.
Infectious bovine rhinotracheitis	--	23	10 35 90	1.5	Survival rate of stored airborne virus greatest at 90% RH. Survival greater at 10% RH than at 35% RH.
Influenza virus	PR8	room temperature	15-40 50-90	--	Death rate of generated aerosol high at 50-90% RH and low in the range of 15-40% RH.
Influenza virus, Type A	PR8	20.5-24.0	20-22 34-36 50-51 64-65 81	23	Sudden increase in viable decay rate of stored aerosol cloud at >35% RH. At 50, 65, 80% RH, viable decay proceeded at closely similar rates.
Measles virus	Edmonston	20-21	20-90	--	Survival of aerosol cloud good at ~20-40% RH; virus decay increased quickly in the range of 50-70% RH. At 80-90% RH, survival rate improved.
Newcastle disease virus	GB-Texas	23	10 35 90	1.5	Survival of stored airborne virus greater at 10% RH than at 35 or 90% RH.
Poliomyelitis virus, Type I	CS 7	room temperature	45-95	--	Inactivation of generated aerosol slow at 50-95% RH and very fast at <50% RH.
Poliomyelitis virus, Type I	Brunhilde	20.5-23.5	18-51 64-65 80-81	23	Survival of stored aerosol cloud greatest at 80-81% RH. Sudden increase in viable decay rate when RH was lowered to 50%; improved survival at 20-35% RH.
Vaccina virus	--	21.0-23.0	18-19 48-51 82-84	23	Survival of stored aerosol cloud greatest at 18-19% RH.
Venezuelan equine encephalomyelitis virus	--	21.0-23.0	19-23 50 81-86	23	Survival of stored aerosol cloud greatest at 19-23% RH.
Vesicular stomatitis virus	--	23	10 35 90	1.5	Survival rate of stored airborne virus greatest at 10% RH. Survival greater at 90% RH than at 35% RH.

TABLE D-1 (CONTINUED)

EFFECTS OF RELATIVE HUMIDITY ON HEALTH

VIRUSES (continued)

rne Viruses

ure Conditions		Effects	Reference
RH %	Time Hr.		
10 35 90	1.5	Survival rate of stored airborne virus greatest at 90% RH. At 35% RH, survival was extremely poor; at 10% RH, survival was considerably improved.	Songer, 1967
10 35 90	1.5	Survival rate of stored airborne virus greatest at 90% RH. Survival greater at 10% RH than at 35% RH.	Songer, 1967
15–40 50–90	--	Death rate of generated aerosol high at 50-90% RH and low in the range of 15–40% RH.	Hemmes *et al*., 1960
20–22 34–36 50–51 64–65 81	23	Sudden increase in viable decay rate of stored aerosol cloud at >35% RH. At 50, 65, 80% RH, viable decay proceeded at closely similar rates.	Harper, 1961
20–90	--	Survival of aerosol cloud good at ~20-40% RH; virus decay increased quickly in the range of 50-70% RH. At 80-90% RH, survival rate improved.	DeJong and Winkler, 1964
10 35 90	1.5	Survival of stored airborne virus greater at 10% RH than at 35 or 90% RH.	Songer, 1967
45–95	--	Inactivation of generated aerosol slow at 50–95% RH and very fast at <50% RH.	Hemmes *et al*., 1960
18–51 64–65 80–81	23	Survival of stored aerosol cloud greatest at 80-81% RH. Sudden increase in viable decay rate when RH was lowered to 50%; improved survival at 20-35% RH.	Harper, 1961
18–19 48–51 82–84	23	Survival of stored aerosol cloud greatest at 18-19% RH.	Harper, 1961
19–23 50 81–86	23	Survival of stored aerosol cloud greatest at 19-23% RH.	Harper, 1961
10 35 90	1.5	Survival rate of stored airborne virus greatest at 10% RH. Survival greater at 90% RH than at 35% RH.	Songer, 1967

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E. ORGANIZATIONS CONTACTED

1. Government Agencies and Associations

Air Conditioning and Refrigeration Institute
American Gas Association
Architectural Aluminum Manufacturers Association
American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
Mineral Wool Association
National Bureau of Standards
National Conference of States on Building Codes and Standards
Building Code Authorities in the Following Sates:

- Arizona
- California
- Georgia
- Florida
- Louisiana
- Massachusetts
- Minnesota
- Missouri
- New Jersey
- New Mexico
- New York
- South Carolina

2. Industry

AIA Research Corp., Washington D. C.
American Meter Corp, Hawthorne, Ca.
Certain-Teed Products Corp, Valley Forge, Pa.
General Electric Co., Louisville, Ky.
GTE Sylvania-Electric Products, Inc., Danvers, Ma.
Honeywell, Inc., Minneapolis, Minn.
Levitt & Sons Inc., Denver, Co.
Owens-Corning Fiberglas Corp., Toledo, Ohio
PPG Industries, Pittsburgh, Pa.
Robertshaw Control Co., Richmond, Va.
Sprague Meter Company, Bridgeport, Ct.
Westinghouse Electric Company, Pittsburgh, Pa.
W. F. Spiegle, Inc., Jenkintown, Pa.